BAMBOO, PEOPLE AND THE ENVIRONMENT

Proceedings of the Vth International Bamboo Workshop
and the IV International Bamboo Congress
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Biodiversity and Genetic Conservation

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Foreword

The Vth INBAR International Bamboo Workshop was jointly held with the IV International Bamboo Congress from 19 to 22 June 1995 in Ubud, Bali. The Workshop was organized under the auspices of the International Network for Bamboo and Rattan (INBAR) and the Congress under the banner of the International Bamboo Association (IBA).

Over 600 people from different walks of life – scientists, engineers, architects, designers, crafts people, environmentalists, rural development experts, government officials and plain bamboo enthusiasts-congregated at Ubud to partake in the five-day event of the year. Several representatives of the Indonesian government, international organizations, diplomatic community, and local and foreign media attended the Bali Congress. A large number of scientists participated in the intensive and keen scientific discussions at the 15 scientific sessions.

That the event was such a huge success was largely due to the painstaking efforts put in by a number of people from the organizations involved, particularly by Dr Elizabeth Widjaja, Ms Linda Garland and their team at the Environmental Bamboo Foundation, which was the local host. It also made a great difference that the International Plant Genetic Resources Institute (IPGRI) and the Government of the Netherlands actively supported some of the scientific sessions. It would only be appropriate here to thank all of them.

The Bali Congress was held at a time when bamboo and other forest resources .were being increasingly subjected to overexploitation and unsustainable use. This aspect was integral to the theme of the event – Bamboo, People and the Environment. Several papers and posters were presented at the Congress on subjects ranging from bamboo propagation techniques to anatomical studies on pachymorph bamboos, from the role of bamboo in rural development to use of bamboo in religious rituals, from bamboo conservation strategies to use of molecular markers, and from design input into bamboo crafts to bamboo building codes.

In compiling the proceedings, we decided to make a departure from the previous practice of gathering all the papers in one large volume. We felt that segregating the papers presented at the sessions into different subject areas would provide a sharper focus, and presenting them as handy volumes would serve the readers better. Consequently, the proceedings are being published in four volumes: Propagation and Management, Biodiversity and Genetic Conservation, Engineering and Utilization, and Socio-economics and Culture. The last volume, Socio-economics and Culture, also contains the list of participants.

We have taken care to ensure that this publication imbibe the essence of the Bali Congress. Dr Elizabeth Widjaja, Dr P.M. Ganapathy, Dr Jules Janssen, Dr V. Ramanatha Rao, Mr. Brian Belcher and Prof. Trevor Williams have very kindly assisted with the technical editing of the papers, and we thank them for their time. We hope that you, as reader, would derive as much satisfaction as we did in bringing *Bamboo, People and the Environ-merit* to you.

I.V. Ramanuja Rao
Cherla B. Sastry
General Editors

Preface

This volume is the second of the four-volume series *Bamboo, People and the Environment,* which cover the proceedings of the Vth INBAR International Bamboo Workshop and the IVth International Bamboo Congress, jointly held in Indonesia from 19 to 22 June 1995. It contains papers presented in the subject areas of bamboo biodiversity and genetic conservation.

INBAR, and the informal research network which preceded it, has always recognized that utilization of the resource base depends on its sustained well-being. Much of the research promoted by national programs has had to address shortages of supply caused by overexploitation of resource and degradation of ecosystems. The sustained well-being of the resource base depends on effective conservation and adequate description of the resource through taxonomic research. However, if sustained utilization is to meet expected demands, understanding the patterns of diversity of economically important species is imperative.

Whereas the emphasis in the 1980s was on development of taxonomic monographs, the urgent need by the mid-1990s has become the utilization of genetic diversity in a time-frame much shorter than what was anticipated. Yet, research in this area has lagged from the lack of appropriate expertise in all regions where bamboo biodiversity exists.

The papers in this volume touch upon several areas of research which need to be expanded rapidly: population studies, delimiting patterns of variation using genetic markers, focus on gene pools and genetic resources rather than on species, and continued taxonomic research.

Only when much more information in the above areas is readily available, will truly effective in situ conservation be upgraded to contain adequate representation of genetic diversity in germplasm conditions. It is also apparent that conservation strategies will have to be innovative and flexible since so much diversity is nurtured by local people and communities.

The challenges to the research community are large, but they must be faced if the spirit of Agenda 21 of the Earth Summit is to be translated into practice and bamboo continue to sustain the livelihoods of so many people.

V. Ramanatha Rao
I.V. Ramanuja Rao
Editors

Bamboo, Biodiversity and Conservation in Asia

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Abstract

Bamboo is indeed one of nature's miracles, and its strength and structure enable it to be put to diverse uses. In Asia, bamboo is the stuff of life for many communities, and it is no exaggeration to speak of a Bamboo Civilization in the region. While bamboo has historically been so common that no particular management was considered necessary, increasing demands from the rural population, urban centres and international trade are leading to declining stocks. This paper examines the cultural and ecological importance of bamboo and suggests that its multiple uses can provide a basis to create incentives for its conservation.

Introduction

> "Their strength, lightness, smoothness, straightness, roundness, and hollowness, the facility and regularity with which they can be split, their many different sizes, the varying length of their joints, the ease with which they can be cut and with which holes can be made through them, their hardness outside, their freedom from any pronounced taste or smell, their great abundance, and the rapidity of their growth and increase, are all qualities which render them useful for a hundred different purposes, to serve with other materials which require much more labour and preparation. The bamboo is one of the most wonderful and most beautiful productions of the tropics." (Wallace, 1869).

Bamboo is an extremely useful grass which is in high demand throughout Asia, with a commercial economic value of at least US$7 billion per year (Stevens 1995). Because of the bulkiness of bamboo culms and the high freight-value ratio of bamboo, the radius of economical transport is limited and hence, most bamboo is used near the centres of production. Even so, Liese (1985) reports that in 1979, Taiwan alone exported bamboo and bamboo goods to more than 80 countries, earning US$116 million. The value of Taiwan's exports has undoubtedly increased substantially since then.

Bamboo is the most diverse group of plants in the grass family, and the most primitive sub-family. They are distinguished by having woody culms and complex branching, a complex and generally robust rhizome system, and infrequent flowering (Soderstrom and Calderon 1979). Bamboo has a cosmopolitan distribution, ranging from 46°N to 47°S latitude, reaching elevations as high as 4 000 m in the Himalayas and parts of China. Bamboo is very adaptable, with some species being deciduous and others evergreen; at least some species seem to be able to change this habit when necessary.

While bamboo is widespread, it is seldom collected by botanists because the plants flower rarely and are very cumbersome to collect. Taxonomically critical vegetative parts, such as new culm leaves and branch complements, also need to be sampled if the collection is to be taxonomically helpful. Thus the taxonomy of bamboo remains relatively poorly understood, though a general consensus seems to be that bamboo numbers between 60 and 90 genera, with 1 I00 to 1 500 species (Dransfield 1988; Williams and Rao 1994).

Bamboos are often divided inro cultivated or village bamboos and native or forest bamboos (Holttum 1958). Native bamboo tends to be a plant of the secondary forest. In Sumatra, patches of bamboo in the forest almost invariably indicate sites disturbed intensively by people at some time in the past (Whitten et al. 1984). In Borneo, cultivated bamboos are found only in localities once under cultivation or near habitations, and indeed various species have been introduced by forest-dwelling people who value their presence (Beccari 1904). Bamboo seems to have followed many ancient maritime spice routes between China, Indonesia, Sri Lanka and India, sometimes making it difficult to establish the centre of origin for some species (Soderstrom and Calderon 1979).

Bamboo can meet industrial and rural requirements, check erosion and conserve soil. It can be directly sown or planted as rhizomes, culm cuttings or nursery-raised seedlings. Because of its extensive rhizome and root system, bamboo is useful for soil erosion control, and road and steam embankment stabilization. Bamboo can be extremely important in providing vegetative cover to deforested areas. It produces a leafy mulch on the soil surface, its foliage provides shade and protection against rains, and its habit of producing new culms from rhizomes enables the culms to be harvested without disturbing the soil (Soderstrom and Calderon 1979).

Bamboo forests may yield more raw material more quickly for rural people than other forests, or even certain forest plantations. Some species of bamboo produce annual yields of over 10 t/ha, though Liese (1985) concludes that the sustainable yield can generally be assumed to be 2-4t/ ha as understorey and 5-12 t/ha from plantations, with higher values on good soils aided by fertilizers and scientific management. While bamboo has historically been so common that no particular management was considered necessary, increasing demands from rural population, urban centres and international trade are leading to declining stocks and increasing concern about conservation. On the other hand, its multiple uses can provide a basis to create incentives for its conservation in support of development. This paper will review the cultural and biological importance of bamboo to demonstrate why its conservation is important, outline some of the conservation steps that are being taken, and recommend additional actions required.

Cultural Values of Bamboo

Porterfield (1933) suggested that “bamboo is one of those providential developments in nature which, like the horse, the cow, wheat and cotton, have been indirectly responsible for man’s own evolution.” In many parts of Asia, life symbolically starts with bamboo, as a bamboo knife is used to slice the umbilical cord of newborn babies. Bamboo also plays a role in some rites of passage; for example, in Malaysia, a bamboo knife is used for performing circumcision ceremonies (Skeat 1900). Life can also end with bamboo, as it has been converted into numerous kinds of weapons, ranging from the infamous punji stakes to arrows, spears and other weapons. Balinese warriors fought the Dutch invaders with bamboo spears.

In China, bamboo is one of the four noble plants. the others being the orchid, the plum tree and the chrysanthemum. Sharma (1982) reports that 800 years ago, the Chinese poet Pou Sou-Long wrote: “A meal should have meat and a house should have bamboo. Without meat we become thin, without bamboo we lose serenity and culture itself.” Bamboo may have stimulated new ways to approach old problems in China. For example, it is widely believed that the early Chinese ship builders derived the concept of water-tight bulkhead from the natural internal walls in the nodes of the bamboo stem. Bulkheads were fitted in Chinese junks 2 000 years before they appeared in the West.

It is not surprising that such an important resource is sometimes given ceremonial value. In Bali, for example, "bamboo is considered an extremely powerful plant. Only old people may tackle the dangerous job of planting it or digging it out, and the first lump of earth dug must be thrown as far away as possible. It is said that if this earth touches someone, he will surely die, and it is only on certain days that work concerning bamboo may be safely undertaken." (Covarrubias 1937).

The Torajas of Sulawesi believe that their ancestors came from mainland Southeast Asia, so their houses are sited facing north and are built in the shape of the boats in which their ancestors are believed to have sailed. The houses are tall and narrow, with wall often built with bamboo and a roof of split bamboo covered by thatch.

However, bearing out the adage that the value of a resource depends on how it is used, bamboo sometimes has led to significant economic loss to some Asian countries. In 552 A.D., the eggs of the silkworm were first smuggled by monks in bamboo sticks from China to Constantinople, which led to the collapse of the profitable Chinese silk trade (Liese 1985).

Bamboo and the arts

In the rich art of China and Japan, bamboo provides the paper, the brush and the artist's subject. Some of the fine brushes used in Chinese paintings are made of fine bamboo shavings with a small holder of bamboo.

Bamboo is widely used for musical instruments of three types – percussion or hammer instruments, blown or wind instruments, and stringed instruments. More than 20 musical instruments in West Java are made from bamboo. The flute may have been invented by a caveman toying with hollow bamboo; at any rate, bamboo flutes are an ancient feature in southeast Asia, as they are known to every indigenous group in the region (Widjaja and Dransfield 1989). Bamboo provides both tubes and reeds for flutes, ranging from simple tubes to complex pan-pipes. The famous bamboo organ at Las Pinas in the Philippines was constructed 'in 1818 from 950 bamboo culms, and is still in use (though some culms have been replaced). A percussion instrument used in Indonesia and Thailand is based on hollow bamboo sound tubes tapped by moving hammers which are extended upwards; shaking the instrument causes the tapping note. A sort of xylophone widely used in Southeast Asia is made of segments of bamboo of different lengths strung together to produce the notes of the scale and played with two sticks. Not all bamboo instruments need such energy; in some villages, bamboos are carved so that breezes blowing through the perforations produce melodious musical tones, often of great complexity (Kurz 1876).

Orang Aslis in Malaysia make beautifully incised and decorated combs from pieces of split bamboo. Many of these combs are rightly considered works of art, and some of them have certain ritual connotations, protecting the individual against evil spirits (Carey 1976). For many of the native peoples of Borneo, the working of designs on the surface of pieces of bamboo is an important expression of their artistic abilities – decorating their drinking cups, tobacco boxes, and tubes for carrying flint and steel. Some of these are in relief and others are printed in black or red (Hose and McDougal 1912).

A popular dance in many Asian countries is the Bamboo Pole Dance, where two people sit and hold two bamboo poles at both ends. As the dancer's feet skip in and out of the space between the poles, the bamboos are brought together in time with the rhythm. Suspense is introduced because a dancer missing the beat will have his or her foot painfully caught between the thick bamboo poles.

Bamboo also has an important role in the literacy of Southeast Asia. In the Philippines, before paper arrived, bamboo was used to record the written word, using as a pen the point of a knife or other bit of iron, with which letters were engraved on the smooth side of the bamboo (Colin 1663).

Bamboo has inspired flowery descriptions by scientists. Wallace (1878) said that "A fine clump of large bamboos is perhaps the most graceful of all vegetable forms, resembling the light and airy plumes of the birds-of-paradise copied on a gigantic scale in living foliage." D'Orleans (1894) described his walk through a bamboo forest in what is today Vietnam: "Every kind of architecture is represented. Here are rounded pillars, others ornamented with arris; there is the ogive, and further on the semi-circular, traves and architraves, low, damp, gloomy vaults and high, bold, graceful arches, full of daylight; nothing could be stronger than this timber work, erected by nature, to support a canopy of verger, which shelters travellers from the rays of the glowing sun."

Bamboo: a resource of many uses

For some forest-dwelling people, the most important of all wild produce is bamboo, which is used to construct houses, household utensils, vessels, tools, weapons, baskets, water pipes, rafts, musical instruments and various ornaments. In fact, Carey (1976) states that “the whole of Temiar (a forest-dwelling group in Peninsular Malaysia) material culture depends on the use of bamboo.” Different varieties are used for different things, including poles for radio aerials, nets, fish traps, fish screens, needles and pens, cooking vessels, hut posts, benches, chairs and fences. Bamboo is an important trade item, and is often floated down rivers in rafts to sell in downstream market towns.

Bamboo was endowed by nature “with so many useful qualities, and delivered them into the hands of mankind so ready for immediate use, that a few sharp cuts sufficed to convert them into all kinds of various utensils.” (Jagor 1875). The many uses of bamboo in China were enumerated as early as the 3rd Century A.D. in a treatise on bamboo (Aero 1980). A list published in Japan in 1903 included 1 048 articles of practical use manufactured from bamboo (Liese 1985), indicating the outstanding utility of this grass. The following list is presented to indicate the imagination and creativity that people have applied to bamboo in helping to earn a living in different environments.

Construction

- In construction, bamboo provides pillars, floors, walls, doors, window frames, rafters, room separators, ceilings and roofs. In Borneo and the Naga Hills of India, large communal houses that may be 100 m long are built of bamboo. Bamboo is used to make guard houses in rice fields, roadside food shops, hot houses for growing mushrooms, smoke houses for drying tobacco or rubber, store houses for rice and other produce, and livestock sheds. Bamboo is also used to make pegs which replace nails. Bamboo scaffolding finds extensive use in Asian cities, even on very tall buildings.
- The meeting houses of some New Guinea villages are 20 m tall and more than 40 m long, with huge bamboo poles set deep into the ground and bent over in the shape of Gothic arches to carry the thickly thatched roof, creating some of the boldest structures built with minimal equipment and technology. Japanese houses are far more sophisticated, but are still typically built of wood, paper and bamboo.

- Many villagers use bamboo shingles, with the large stems split in half and laid with the convex and concave sides alternately facing upwards, with their edges overlapping. In coastal areas, roofs often are made of thatch woven from nipa palm around long slivrers of bamboo.
- In Tonga, headrests are made of bamboo with hardwood supports.
- Bamboo is used in China to make furniture, often without recourse to nails or glue, as the main framing members are notched and tapered to fit together like the pieces of a puzzle. The seats are commonly made of slender bamboo slats.
- Bamboo is used throughout rural Asia to build bridges of many types and sizes; they can be as long as 25 m, often involving sophisticated technology as suspension bridges, but also with simple technology in the form of pontoon bridges (Kurz 1876).
- With new technology, bamboo is replacing tropical woods in parquet flooring and iron rods in reinforced concrete.
- Bamboo serves shipping as ropes and cables which are of great tensile strength, highly resistant to rot, chafe and stretch, and relatively light to handle. Bamboo is also woven into screens and roofing mats for the deck housing, as well as for providing various booms and poles.

Food and cooking

- The use of bamboo in food and cooking goes far back in history, and starts with making fire – bamboo is used to construct a fire-saw, using bamboo shaving for tinder.
- Edible bamboo shoots earn considerable income. Intensively managed shoot stands will produce about 10 000 kg / ha of shoots per year (Sharma 1982). Exports of bamboo shoots from Taiwan amount to US$50 million per year (Liese 1985). However, in Chinese cooking, bamboo is strictly avoided for ulcer patients.
- Bamboo seeds are consumed as food in times of famine, with seeds of some species comparable to wheat in protein content and to rice in protein quality (Sharma 1982).
- Dried mature leaves are used for deodorizing fish oils.
- Tubers and rice are cooked in a length of bamboo culm, and then steamed or roasted over fire to make “trail food”, taken on hunting trips or to distant rice fields.
- Bamboo is used to construct frameworks for cooking pots over hearths in longhouses, and provides beakers for drinking water, beer and various kinds of liquor.

Hunting and gathering

- Bamboo is made into a wide variety of weapons. In Malaysia, Negritos use bamboo to make blowpipes for hunting small animals such as monkeys and squirrels (Carey 1976), while elsewhere in tropical Asia, bamboo makes blowpipe darts and a quiver for darts. In the Andaman Islands, bamboo reeds are used as fish arrows (Radcliff-Brown 1933,. Bamboo is also widely used to make handles of spears and knives.
- Bamboo helps to reach fruit which is out of reach, as poles for collecting coconuts, durians or mangoes. In certain parts of Borneo, and no doubt elsewhere in tropical Asia, bamboo is used to make pegs which are driven in to a tree to form a sort of ladder for climbing the tree to reach fruit or other resources (Wallace 1859).
- In Sarawak, coastal villagers gather shell fish and worms by quivering a twig of bamboo down a hole and luring up the prey (Harrisson 1970). In more inland areas, fishing is sometimes done with the use of fish poison known as tuba, which is pounded on a bamboo platform built over a pool.
- Bamboo is widely used for making traps for animals or fish, ranging from sophisticated cage traps to simple dead-falls and pit traps with sharpened bamboo stakes at the bottom of the trap.
- Punans in Borneo make bamboo pipes with which they imitate the calls of deer and some birds (Hose and McDougal 1912), thereby luring them close enough to be killed.
- Bamboo makes a carrying pole whose great strength, relative lightness and springiness make it one of the most comfortable ways to transport loads (such as agricultural produce and food items) over long distances.

Industry and agriculture

- In India, bamboo provides almost the entire supply of long-fibre pulping material for the pulp, paper, board and newsprint industry (Sharma 1982). About 70% of the pulp used in making paper in India come from bamboo, with an estimated annual production of 250 000 tonnes (Soderstrom and Calderon 1979).
- Bamboo is used as a lever by which water is raised from wells, and to construct pipes to provide drinking or irrigation water.
- Some species of bamboo are used to make living fences, which are virtually impenetrable to livestock (Kurz 1976).

- Bamboo is used as a raw material for making hats in various parts of Asia, especially Borneo; these are becoming increasingly important in trade.
- High-quality toothpicks and chopsticks are made from bamboo, and are finding an increasing market.
- Bamboo is widely used to make the handles and framework for umbrellas.
- Bamboo makes some of the most prized fishing rods.
- Bamboo is being employed as a filter in sewage treatment plants.

Miscellaneous

- The tiny hair in the wrapping of new bamboo leaves are considered a slow and undetectable poison in Bali (Covarrubias 1937).
- Liese (1985) reports that the rhizomes of *Dendrocalamus hamiltonii* with slight dressing is an exact replica of a rhinoceros horn which fetches fabulous prices for medicinal uses; only an expert can identify the imitation.
- In Malaysia, Semelai villages have windmills made of bamboo to produce a loud and rather eerie sound, which can be heard many kilometres away. In a forested land with few pronounced geographical features, these windmills serve the important purpose of a sort of "homing beacon" (Carey 1976).
- Bamboo provides various medicines. For example, the sap that hardens between nodes is prescribed for asthma. Some species of bamboo in China are used to fight fevers, allay apprehension and restlessness, and detoxify the body. The Chinese also use it medicinally as a tonic for the stomach, as a cure against dysentery, and as a remedy for toothache.

Small wonder that bamboo is so highly valued throughout Asia. Indeed, the long and close association between people and bamboo in Asia led Porterfield (1933) to suggest that archaeologists would be justified in incorporating a definite Bamboo Age, comparable to the Stone Age or Bronze Age, in their historical chronologies for Southeast Asia.

Ponder (1936) says: "In all the length and breadth of Java I doubt if there is a native house that has not its clump of bamboo growing in the garden wherefrom to cut for the thousand-and-one purposes for which it is used. Next to the rice on which they live there is no one thing that could be named which is so utterly indispensable to the people of Java as this native of their jungle, which they now cultivate so universally.” Bamboo clearly deserve much greater attention from those who are seeking to promote sustainable development in Asia.

Bamboo and Biodiversity

Besides the myriad direct human uses, bamboo is important in many other ways. This section will outline the current knowledge on the status and distribution of bamboo, and indicate – at least in a preliminary way – the other species that are especially dependent on bamboo.

Taxonomy and distribution

Dransfield (1988) points out that a formal and overall classification of the woody bamboos has not yet been prepared and broadly accepted, but an estimate of about 60-90 genera seems generally accepted. Sharma (1982) provided a list of I92 species of bamboo from the Asia-Pacific region, including both native and cultivated species. Of the estimated 180 species of bamboo found in Southeast Asia, 100 species are indigenous to the region and have relatively limited distributions. About 30 are found only in cultivation and were probably brought in from other parts of Asia over the past 3 000 years, while about 125 species are growing wild in their natural habitat but have been brought into cultivation in other regions (Widjaja and Dransfield 1989). Clearly, then, the distribution of bamboos has been greatly modified by human intervention.

Despite this taxonomic uncertainty and general paucity of research, some estimates for various parts of Asia are available. These are summarized in Table 1.

The taxonomy of bamboo in Japan is puzzling. Sharma (1982) claimed that Japan has some 670 species of bamboo in 14 genera, covering about 148 000 ha, of which 144 000 ha are private forests owned by farmers. But Liese (1985) reported that Japan has 95 species covering about 125 000 ha and producing about 280 000 tonnes of culms per year. The lower figure on number of species is perhaps more credible, but the message is clear that the temperate areas tend to support more species than the tropical countries.

Bamboo and wildlife

With primary productivity as high as that of many forests, bamboo provides support to many species of wildlife. Some of these, such as

Table 1: Species of bamboo in selected Asian countries

Country	No. of species	Area covered (ha)	Notes
Papua New Guinea	26		
The Philippines	49		
Indonesia	30+		
Malaysia	28	19	endemic to the Peninsula
Thailand	50	1 million	
Burma (Myanmar)	90	2.2million	
Bangladesh	33	0.6 million	
China	300	3.9 million	
India	136	9.6 million	produce 3.3 million tonnes

Sources: Sharma (1382); Liese *(1985);* Dransfield *(1988).*

elephants *(Elephas maximus),* the wild cattle (Bosgaurusand *B. javanicus)* and various species of deer (Cervidae) and primates (including macaques Macaca and leaf monkeys *Presbytis),* pigs (Suidae), rats and mice (Muridae), porcupines (Hystricidae), and squirrels (Sciuridae) are incidental feeders on Southeast Asian bamboos (Lekagul and McNeely 1977). Schaller et al. (1985) report that in China, sambar deer (Cervus *unicolor),* serow (Cupricornis sumatraensis), tufted deer (Elaphodus cephalophus) and takin (Budorcas taxicoor) all feed on bamboo. In Borneo and Sumatra, even orangutans go into bamboo forests to eat the young culms. In the Himalayas, Himalayan black bears feed on several small species of bamboo in high-elevation forests close to the tree line. The impact of these species on bamboo can be considerable. Rodents gnaw rhizomes and the base of culms and seeds, while some species of squirrels eat the growing shoots. Pigs and porcupines also dig up many young plants to eat the rhizomes and young shoots. Elephants can cause considerable damage as they move through bamboo forests, seeming to take pleasure in twisting l0-cm-thick bamboo into complex knots (Lekagul and McNeely 1977).

Perhaps more interesting are the species of wildlife that are especially, sometimes even totally, dependent of bamboo. The most famous of these is certainly the critically endangered giant panda (Ailuropoda melanoleuca), whose distribution is determined by bamboo, though pandas prefer living in forests with a canopy coverage of 70% or more (Schaller et al. 1985). Over 99% of the food of giant pandas consists of bamboo, with an average adult eating about 4 500 kg per year, amounting to an estimated 466 000 shoots and stems, somewhat less than one percent of the available bamboo biomass per year (Schaller et al. 1985). In essence, pandas have specialized on a plant resource available in virtually unlimited amounts at all seasons, though the nutritional quality of bamboo is relatively low.

A closely related species which is equally dependent on bamboo is the red panda (Ailurusfulgens), found from Nepal to Sichuan. The red panda has recently been added to Appendix 1 of the Convention on International Trade in Endangered Species of Flora and Fauna (CITES), indicating that it too is endangered.

Many species of bats feed around bamboo clumps in various parts of Asia. These are primarily insectivorous bats, such as Kitti's hognosed bat (Craseonycteris thonglongyai), a member of a new family of bats discovered in Thailand in 1974. One genus of bats, Tylonyctiris, roosts inside the bamboo culm, usually *Gigantochloascortechinii,* gaining entrance through narrow vertical slits originally made by a beetle. These bats have distinctive footpads and thumb pads enabling them to grip the interior of the bamboo (Lekagul and McNeely 1977). They also have a remarkably flattened skull, which enables them to enter the small slits in the bamboo.

Species of rodent apparently confined to bamboo habitats include the marmoset rat *(Hupulomys longicaudutaus)* – which eats shoots, flowers and fruits of bamboo and lives in the internodes of the bamboo, which it enters through a round hole it has chewed in the internodes -and the pencil-tailed tree mouse *(Chiropodornys gliroides)* (Lekagul and McNeely 1977). One family of rodents, the bamboo rats (Rhizomydae) consisting of two genera and four species, ranging from China south of Yangtze to the eastern Himalayas and south to Sumatra, seem to be generally confined to the bamboo forests, feeding on bamboo roots and shoots, rhizomes, tubers, grass seeds and fallen fruits. They are burrowing animals, with some species weighing as much as four kilograms (Lekagul and McNeely 1977).

With such high productivity, bamboo also supports many species of birds. In addition to the hundreds of species that may feed incidentally in bamboo forests, numerous species favour bamboo or are confined to this habitat (Table 2).

Table 2: Birds which are highly dependent on bamboo

Mountain bamboo-partridge	*(Bambusicola fytchii)*
Long-billed partridge	*(Rbizothera longirostris)*
Yellow-billed grosbeak	(Coccothraustes mig*ratorius)*
Tawny-breasted parrot finch	*(Erythrura hyperythra)*
Pin-tailed parrot finch	*(Erythrura prasina)*
Tickell's blue flycatcher	*(Cyornis tickelliae)*
Hill-blue flycatcher	*(Cyornis banyumas)*
Rufous-chested flycatcher	*(Ficedula dumetoria)*
Mountain tailor bird	*(Orthotomus culculatus)*
Yellow-bellied warbler	*(Abroscopus superciliaris)*
Rufous-faced warbler	*(Abroscopus albogtdaris)*
Golden-spectacled warbler	*(Seicercus burkii)*
Parrot bills	*(Paradoxornis)*
Fulvettas	*(Alcippe)*
Babblers	*(Stachyris)*
Silver-breasted broadbill	*(Serilophus Iunatus)*
Maroon woodpecker	*(Blythipicus rubiginosus)*
Heart-spotted woodpecker	*(Hemicircus canente)*
Bamboo woodpecker	*(Geninulus grantia)*
Laced woodpecker	*(Picus bittatus)*
Speckled piculet	*(Picumnus innominatus)*
White-browed piculet	*(Sasia* ocbracea)

It is clear, therefore, that many species of wildlife depend on bamboo, either partially or entirely. Conserving bamboo will help conserve these species as well.

Conserving Bamboo

In some parts of Asia, most bamboo is extracted directly from forests, with almost 98% coming from natural stands. In other parts, such as Japan, Bali and Java, most bamboo comes from cultivated sources. In any case, very little explicit attempt is made to conserve bamboo, and it appears that most conservation organizations see little need to give attention to bamboo when so many other species seem to deserve higher priority. However, given the many cultural, social, economic and biological values of bamboo as outlined above, it may be timely to give careful consideration to the status and trends of bamboo, and to mobilize international action to conserve the diversity of bamboo.

Conservation problems

Synchronous flowering

Bamboo is characterized by periodic synchronous flowering followed by death and subsequent regeneration. This synchrony may involve a few clumps, a patch, a whole mountainside or a drainage. These, local synchronous flowerings may be complemented by much larger mass flowerings at cycles of 50 to over 120 years. However, in most localities, several species of bamboo occur. So the mass flowering of one species may be compensated by other species which do not flower, thereby keeping food supplies available for those who are dependent on the bamboo. In pther situations, synchronous flowering and death of bamboo permits sudden widespread tree regeneration (Shidei 1974) which may prevent bamboo from regrowing.

Gregarious flowering has profound implications for the species which are dependent on bamboo. For example, gregarious flowering in China has been claimed to contribute to higher mortality rates of giant pandas by reducing their food supply in geographically constrained areas from which emigration is not possible (Schaller et al. 1985). Thus, improved management of bamboo is an important part of conserving giant pandas.

The widespread death of bamboos in such conditions makes them vulnerable to fire damage, and can cause considerable human impacts as well. For example, Soderstrom and Calderon (1979) summarized the implications of the flowering and subsequent death of the bamboo Melocanna *bambusoides* (which flowers once every 30-35 years) around the Bay of Bengal: “Death of the bamboo robs the population of its building material, and the excess of accumulation of bamboo fruits brings on a rapid increase in the rodent population. As the rodents increase, they devour whatever food is available, destroying grain fields and stored food. Such diseases as typhus, typhoid and bubonic plague reach epidemic proportions with the rodent population explosion.” Thus, bamboo is linked through ecological processes to numerous other human interests.

Further, the long growth periods of bamboo before flowering complicates conservation, as it is difficult to store their seeds. Scientists in India have induced one species of bamboo to flower in a test tube, but this was a major effort that has not been widely replicated (Stevens 1995), Bamboo is difficult to hybridize since its flowers are monocarpic, and this helps explain why propagating bamboo by seeds is not very popular. While vegetative propagation is possible, it is seldom practised in captivity. However, new research in India, China, Japan and Bangladesh is finding new ways of promoting propagation.

impact of logging, deforestation and shifting cultivation

Bamboo usually survives logging, though its growth form often is affected by removal of the forest canopy. Where significant deforestation has occurred, including deliberate destruction by warfare or fire (for example, in Vietnam), bamboos have tended to increase and become established in pure stands that may persist for years (Drew 1974), often replacing far more diverse assemblages of bamboo. This is, perhaps, an example of too much of a good thing, requiring intensive management to restore an appropriate balance between bamboo and other species of plants.

In some parts of Thailand, Burma and Laos, shifting cultivation has resulted in expansion of the area of some species of bamboos, often at the expense of other types of vegetation that may contain more species. Again, the issue is one of balance.

Over-harvesting and lack of regeneration

In other cases, bamboo is threatened by lack of regeneration or over-harvesting from the wild. Sharma (1982), for example, reports that bamboo forests in Thailand are threatened with lack of adequate regeneration because of the removal of new shoots. Gigantochloa is the most widely used genus of bamboo in Southeast Asia and is under severe harvesting pressure, but it is also the one that is most important as a habitat for other living beings (especially bats and rats) which seem to be confined to bamboo.

Limited distribution

Bamboo species that are naturally rare or have limited distribution may be especially vulnerable to habitat changes or over-harvesting. According to Dransfield (1988), *Arcemobambos setifera* has been reported from only three localities, and *Bambusu montana, B. pauciflora* and *B. klossii* have been reported from only a few localities. Of the seven species of bamboo which are known in China's Wolong Nature Reserve in Sichuan Province, four are rare or patchy in distribution (Schaller et al. 1985). These species of very restricted distribution deserve special attention as significant alteration of their habitat might lead to extinction. No doubt, further studies will reveal numerous other bamboos which fall into this category.

Schaller et al. (1985) conclude that "The relationship between forests and bamboo is a dynamic one – a function of topography, the frequency and amount of natural disturbances to the vegetation, and the colonizing ability and flowering interval of the bamboo species, to mention just a few variable." A program to conserve bamboo will require an understanding of the cyclic changes in the forest and bamboo community, and better knowledge of the impacts of various management regimes.

Management programs

Management of bamboo in tropical Asia is under a wide range of regimes (Sharma 1982). In the Philippines, bamboo forests have been utilized without any regulatory techniques for their proper exploitation and management, while in Thailand, the Forest Department is not involved in harvesting of bamboo. This lack of management attention has sometimes led to overexploitation, especially from public forests. Incomplete knowledge on how to manage bamboo also can lead to overexploitation, especially on public lands where it is easy to fall into the temptation of felling all mature culms. But this reduces the vitality of the clump, sometimes leading to its death. One form of management practised in India is to harvest the bamboo well before it flowers, thus preventing the stock from flowering itself to death (Kurz 1876). The consensus is that selective felling is generally the best practice, using a system of annual coups worked in rotation.

In India, the sale of bamboo for pulp is based on forest area, with a lump sum paid. This sometimes includes a monopoly fee along with a royalty fee based on the number of culms. The purchaser may acquire the standing bamboo and harvest it himself, or he may leave the cutting to the owner who mostly does it more carefully. In the Philippines, cutting from government-owned forests is controlled by village management plans and may be carried out solely by residents of the particular area.

How to conserve bamboo biodiversity

The preceding discussion suggests that a new effort to conserve bamboo is well justified by the combination of high economic, social, ecological and cultural values; inadequate knowledge of bamboo taxonomy, status, distribution, biology and ecology; and growing demand leading to increased pressure on the bamboo resources. Action will be required by at least the following groups.

- SCIENTISTS need to expand their field collecting activities to support further work in taxonomy as a basis for investigating additional uses of bamboo, and to assess the status and distribution of the various species. Any new effort towards sustainable use of bamboo and expanding the range of species to be used will require significant work to clarify the taxonomy of this highly complex family. Ecological relationships with other species also need to be investigated, with a view to improve management.

It would be extremely useful to prepare an identification key or identification manual for bamboo based on vegetative characters rather than flowers, since the latter emerge so infrequently. While a global key or manual is probably impossible, national or regional identification tools are clearly feasible for at least some countries. Scientists also need to conduct further research on the lifecycle of the various bamboos and the reasons for mass flowering, in hope of developing the capacity to predict flowering and initiate appropriate management procedures.

- CONSERVATION DEPARTMENTS should seek full information on the distribution of bamboo within protected areas and ensure that all wild species of bamboo are covered by the protected areas of the country. They need to be particularly aware of the successional stages in which bamboos occur, and instigate appropriate management regimes to ensure a distribution of appropriate successional stages within protected areas. For example, species demanding early successional stages may disappear if the vegetation of a protected area is not appropriately managed. Managing protected areas to conserve climax vegetation may lead to the loss of at least some species of bamboo.

Conservation departments also need to consider how to manage and promote natural regeneration following gregarious flowering and death of bamboos. When bamboo occurs within the boundaries of protected areas, harvesting may be technically illegal, thus giving rise to tensions between the conservation and development interests. To earn support from local villagers, protected area managers should consider allowing at least some harvesting of bamboo under certain conditions, and might involve local people in management programs.

- BOTANICAL GARDENS need to develop further collections and utilize these in research and public education, such as in the botanical gardens of Bogor and

Bali (Indonesia), Perideniya (Sri Lanka) and Singapore. More botanical gardens should raise different kinds of bamboo both to demonstrate the great diversity of these grasses and to build public awareness. Botanical gardens should also investigate ways of raising bamboo artificially, from seeds or by planting rhizomes, culm cuttings and nursery-raised seedlings, and increase their research investments in this regard.

■ FOREST MINISTRIES need to recognize the great value of bamboos, especially for local communities, and ensure that research in forest management gives full consideration to bamboo. Research on optimal felling cycles and intensities for the different species should be conducted, perhaps beginning with quantitative assessments of bamboo resources. This will involve determining growth rates and yields.

Forest ministries should investigate the possibility of planting bamboo under tree plantations as a means of increasing the diversity, value and productivity of the plantations, and providing more benefits to local people. This may require developing forestry regulations that include bamboo, perhaps building on precedents in India.

In Indonesia, the Ministry of Forestry has been cultivating bamboo in disturbed habitats to meet the demands of the paper industry and to prevent soil erosion (Widjaja and Dransfield 1989). This effort should be expanded and emulated elsewhere in the region, with the support of relevant international organizations.

● MINISTRIES OF COMMERCE AND INDUSTRY need to recognize the value of bamboos that are consumed locally as an important contributor to rural welfare. While such values seldom enter national income accounts, they may be substantial and contribute to a more complete picture of national well-being.

These ministries should also ensure that accurate statistics on local, national and international trade involving bamboos are collected and publicized, as a way of demonstrating to decision-makers the economic importance of bamboo.

The use of various kinds of bamboo for construction should be further investigated and promoted, for example, by providing appropriate incentives to the private sector.

● NATIONAL GOVERNMENTS should give increased attention to the multiple values of bamboo, including biological, cultural and developmental. For example, traditional uses of bamboos for musical instruments should be publicized, helping to preserve the traditional heritage of the people in the region and develop the industry on a commercial basis. This would be especially relevant in Indonesia, Malaysia, Thailand and the Philippines.

Further, it appears that many species of bamboos are especially likely to flower during years of drought (Kurz 1876). Some experts suggest that bamboo reserves might be seen as useful reservoirs for providing food during periods of famine, as the bamboo seeds produced following flowering are highly nutritious.

- THE PRIVATE SECTOR should seek more opportunities to tap into the growing market for bamboo products. Sophisticated technology has enabled bamboo to enter the highly competitive world market in the form of pulp for paper, parquet for floors, a new form of plywood made from bamboo, and veneers. Canned bamboo shoots are also finding a growing market internationally. This may require the provision of economic incentives to farmers. For example, in Thailand, bamboo industries encourage farmers to establish bamboo plantations by offering incentives such as guaranteed prices, technical advice, and cheap seedlings and cuttings. Large bamboo plantations are now being established by private companies in southern Sumatra and eastern Java to fill the needs of bamboo-based industries for bamboo shoots, chopsticks, toothpicks and fancy handicrafts (Widjaja and Dransfield 1989).

- LOCAL PEOPLE should be given increased responsibility for managing their own bamboo resources. It is apparent that local people are capable of taking far greater responsibility for managing bamboo resources on public land. For example, Rutter (1929) reports that in North Borneo, some Dyak villages claim as reserves tracts of land containing jungle products, or individuals or groups of owners may assert a right over clumps of wild bamboo. Penalties for infringement of rights are enforced by the village and are payable by money or chickens.

Particular attention should be given to the cultivated varieties of bamboo, especially those which support local village requirements. For example, environmentally safe and readily available preservatives would greatly extend the useful life of bamboos used in construction of houses, bridges and so forth.

In Nepal, some ethnic groups have ritual constraints against planting bamboo. While they greatly appreciate the benefits of bamboos, they believe that planting seedlings will result in the death of the planter; however, planting vegetative material may not have such grave consequences

(Gilmour, pers. comm.). Clearly, flexibility is the key in involving local people in bamboo management.

Conclusion

Widjaja and Dransfield (1989) consider the future prospects of bamboo to be bright, especially with increasing inputs from modern technology in bamboo production. Bamboo is of outstanding cultural, economic and biological importance throughout Asia, but increasing human populations and expanding demands on resources require a more carefully considered approach to managing bamboo. Such an approach should include:

- scientific research to better understand the taxonomy, distribution and biology of bamboo;
- increasing incentives to farmers to grow bamboo and to use existing bamboo on a sustainable basis;
- increased investment by the private sector (supported by appropriate government incentives);
- public education, especially through botanical gardens; and
- the establishment of protected areas devoted to the conservation of bamboo and the species dependent on it.

Such a program will help ensure that bamboo makes as great a contribution to the future of human welfare in Asia as it has to the history of humanity in this region.

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Progress and Prospects in Genetic Diversity Studies on Bamboo and its Conservation

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Abstract

In recent years, substantial progress is being made on the study of bamboos. Priority species as well as further research needs have been identified, and the area of documentation of information on bamboos has seen considerable advances. However, inventories of natural populations reveal a high proportion of undescribed taxa, indicating that much of genetic diversity and biodiversity remain undocumented. Inventories are not complete in many countries, especially with regard to the identity of taxa. Additionally, information on the distribution, ecology and infraspecific variation of most bamboo species is inadequate, and biodiversity in its broader sense remains largely unexplored. Nevertheless, knowledge of the taxonomic characters which can be used to separate or group bamboos is steadily growing. Advances in modern taxonomic techniques are providing powerful tools for a more objective classification of bamboos. Cladistic analysis allows many different characters to be considered together, avoiding the often contentious emphasis on particuar characters. Molecular data from DNA extracts are now becoming available to back up or help review the classification systems based on morphological knowledge and concepts. Such studies, which are urgently required on the priority species, will also help understand the position of bamboos in relation to other grasses, as well as the relationship between bamboos from different continents. Improved taxonomic data, along with information on the genetic diversity in bamboos, will assist effective conservation measures and efficient use of the bamboo resource.

Introduction

Bamboos are a non-timber forest product of major relevance to millions of people in the tropical region. A better understanding of local bamboo harvesting and management systems, as well as of the traditional knowledge about the species, is needed to give tropical forests time to rejuvenate without hampering the livelihood of its dependents. Bamboo is also an alternative to those whose agricultural needs are centred around the slash and burn method. With its far-reaching potential for economic growth, bamboo would be ideal for ensuring a steady source of income, while simultaneously facilitating forest conservation.

Current extraction practices are leading to severe genetic erosion of the resource base and hence, the conservation of bamboo and rattan genetic resources is becoming critical. However, the information needed to develop and promote complementary conservation strategies and use is lacking. There is an urgent need to promote studies that would generate this much-needed information. Genetic diversity, knowledge of which is essential for efficient conservation and use of the material, has not received adequate attention, probably because of the complexity of the species or varieties that need to be collected, described and conserved.

Collection, conservation and handling of genetic resources of bamboo are very different from the established methods for other species. These may be analogies with tree germplasm conservation, but the great number of economic bamboo species and the limited knowledge base make concerted studies very much needed. In addition, seed production and storage are problematical and there are several unknown aspects which need to be tackled.

- In this situation, bamboo-related activities need a priority setting as follows:
- Assessment of the status of bamboo genetic resources and the degree of threat of genetic erosion, conservation priorities, and development of a database.
- Clear taxonomy and a simple practical key for species of economic importance.
- Studies on geographical variation and genetic diversity, linked with training wherever possible.
- Ethno-botanical studies focusing on the traditional knowledge and management of bamboo.

- Assisting in the exploration and collection of germplasm, and conduct of eco-geographic studies.
- Technology development for long-term conservation, including in vitro culture methods for ex *situ* conservation.
- Development of sustainable in *situ* conservation strategies.

This paper briefly reviews the available information on taxonomy, biodiversity and genetic diversity, since interspecific and infraspecific variations are the basis of genetic conservation of any gene pool. Attempt will also be made to indicate a few areas that need urgent attention.

Taxonomy of Bamboos

Enumeration

The impetus given to bamboo research over the past two decades has resulted in taxonomic enumerations in many countries, and has also stimulated much greater exchange of information. There are still several countries of Southeast Asia and the Pacific that need to be surveyed very intensively, including northeastern India bordering Myanmar. China continues to run active taxonomic programs in several provinces with many experienced taxonomists, gathering useful data. Inventories of cultivated and wild species are being produced in many other countries also, and the genetic delimitation of problem groups is being tackled (Clark 1989; Wong 1993; Alam 1994; Stapleton 1994a, b, 1995; Widjaja 1994). Inventories of bamboo species from larger areas are beginning to appear as collaborative undertakings (Zhu Shilin et al. 1994; Dransfield and Widjaja 1995).

Where taxonomic treatments have concentrated on species that are well known, such as those held in national collections (Bennet and Gaur 1990), there has still been a large amount of work involved in sorting out the nomenclature of the plants. Several different names have often been applied to even the better-known bamboos. For example, the common thorny bamboo of India was first described as Arundo Bambos, but was later called *Bambos arundinacea, Bambusa arundinacea* and *Bambusa bambos,* although some of these names might possibly have first referred to *Bambusa vulgaris* instead. Sharma and Amarinder Singh (1994) conclude that the correct name for the thorny bamboo of India is *Bambusa arundinacea* (Retz) Willd. and not *Bambusa bambos* (L) Voss. Deciding which of the several published names to use can be a difficult task even for well-known species. When inventories of rarer wild bamboos are undertaken, a large proportion are usually found to represent completely new taxa. Widjaja (1994) found that 23 out of the 56 species in Sumatra had not been described before. Similarly, Stapleton (1994a, b, 1995) found that 11 out of the 42 species in Nepal and Bhutan were new. Much knowledge on the identification and distribution of forest bamboos can be found among rural populations. It should be a priority to gather this indigenous knowledge before it disappears along with the forests for ever.

To initiate the work, however, it becomes necessary to identify a few species to focus upon. One such exercise had been done by an INBAR project, in which a group of experts determined the priority species based on available information (Williams and Rao 1994). The criteria that were used for identifying these priorities included: utilization (relative importance to countries and regions in terms of current use, and potential importance to countries and regions), cultivation (knowledge on the degree of domestication and commercialization, and potential for the generation of such knowledge), products and processing (current product values, likely increase in value and potential), genetic resources (materials currently available, degree of genetic erosion and needs of genetic resources programs, including exchange) and agro-ecology (suitability to agro-ecological zones and for use in special conditions). In addition, some countries indicated their five most important species. Although some of these were outside the list of the priority species, they were listed as species of second priority. Much of the work that is being done in Asia is focused on these listed species.

Description: taxonomic characters

Any documentation or taxonomic treatment of the bamboos involves morphological characters by which the bamboos can be described, separated into species, and grouped into genera. Since many of these diagnostic characters are not uniformly applicable to all species, descriptors need to be prepared (Williams and Rao 1994). However, it must be recognized that the commercial sector as well as the communities do not wait for taxonomic definitions, and severe erosion from uncontrolled exploitation of the bamboo resources is continuing. Hence, the urgent need is for a list of traits that can be used by a large number of people, including administrators and field workers, so that some sort of assessment can be made of the loss that is occurring every day. In the mean time, the taxonomic techniques may be refined to better understand and classify the taxonomic diversity in bamboos.

Traditional taxonomy has concentrated principally on the morphological characteristics of the plant, especially those of the flowers. This has been problematic in the case of bamboos since the number of characters is limited and flowers are often not available. Disagreement among taxonomists usually stems from the different interpretations of characters, often with confusion over terminology, or from the emphasis placed on certain characters. To overcome these problems, it is necessary to understand better the characters currently used and to find new characters. Attempts to view the anatomy of bamboos as the solution to the problems of classification and identification have not been as successful as at first hoped. Anatomical characters of leaf have been useful in separating higher orders such as subfamilies and tribes (Soderstrom and Ellis 1988), but attempts to use them at the generic level (Soderstrom and Ellis 1982; Ding and Zhao 1994) have not been very successful. Culm anatomy shows substantial variation, but it is difficult to define different character states objectively. McClure (1966, 1973) made several perceptive observations on the morphology of the rhizome, branching patterns, culm sheath and the inflorescence. These characters still require further critical analysis and the terminology he applied needs redefinition. Study of vegetative branch complement structure in temperate Himalayan bamboos has revealed new characters, such as prophyll keeling and branch replication (Stapleton 1994b). They are objective and seem to be particularly useful at the generic level. Similar characters of inflorescence branching in tropical bamboos are also of use (Stapleton 1994a). This information has basically come out of the survey and inventory work, thus highlighting the importance of inventory work in bamboos for obtaining basic data for descriptions.

New taxonomic techniques

It often helps to reduce conflict between taxonomists if characters are considered in conjunction, rather than in isolation. But progress on this front has been slow. While traditional classifications tended to concentrate on a small number of characters, modern taxonomic techniques such as cladistic analysis attempt to synthesize variation in as many different characters as possible. The cladistic approach places species together only if they share a derived character state. The primitive character state is determined by examining the related groups of species, the fossil record or ontogeny. Reliance on overall morphological similarity (phenetic) as an estimate of phylogenetic relationships, rather than on shared derived character states (cladistic), can be misleading. Hence, cladistic analysis provides a more reliable assessment of the relationships between the different plants; but it requires more in-depth knowledge of bamboos than is presently available from either descriptions or herbarium material. A more consistent use of terminology is also required to allow better comparison of descriptions.

Cladistic analysis is ideally suited to the latest molecular taxonomic methods, in which certain mutations in the genetic code are recorded or DNA sections are sequenced in detail. Molecular techniques provide for a large number of new characters, measured in a totally objective manner. Parts of the genetic code that change very slowly are useful at higher taxonomic levels, such as the subfamily or tribe. Sequences that change rapidly are useful to show relationships between species. The choice of molecule or DNA sequence to be examined is an important first step in any evolutionary or systematic study. Knowledge of rates of change, amounts of variation at different taxonomic levels, considerations of homology and degree of expected homoplasy is essential before and after data collection. As more and more studies involving a given molecule or sequence are done, the value or limitations of each molecule becomes more evident.

Certain portions of a given molecule or DNA sequence evolve at quite different rates, which creates problems for cladistic analysis of molecular data. It has been demonstrated that when large differences in rates of evolutionary change exist between characters, cladistic methods that attempt to minimize the total number of character state changes (parsimony) do not work as well as other methods, such as character compatibility or likelihood estimation (Sytsma 1990). There is very little information on these aspects of bamboo and there is a need to intensify work on these lines. However, as the techniques become simpler to use and the equipment required becomes cheaper, molecular data would become increasingly more important in plant taxonomy and genetics, especially in solving problems of generic delimitation in the bamboos because of the scarcity of flowers and the absence of fossil records. Publication of the first comparison of a sample of Asian bamboos using molecular techniques was a recent landmark in bamboo taxonomy (Watanabe et al. 1994). Further studies involving a wider sample of species are underway in several institutions, including Iowa State University and the Royal Botanic Gardens at Kew.

Research on plant genetic resources (PGR), integrating many fields of study, greatly helps in understanding the evolution ofcultivated plants and their wild relatives (Hanelt 1988). For PGR conservation and use, it is important to have a sound comprehension of the evolution of a given species, and its relationship to other species belonging to the same gene pool – including the traditionally distinguished primary, secondary and tertiary gene pools - as well as to more distant relatives (Engels 1993; Rao and Riley 1994).

Historically, it was mainly morphological information that was used to study and understand systematics, species relationships and evolution. This was followed by the use of biochemical markers and isozymes to study interspecific relationship. A major strength of molecular genetic analysis is that it provides numerous independent molecular characters that can often accurately define monophyletic lineages. The use of molecular markers can involve two separate steps. The first one is to address questions about phylogenetic relationships. Next step is to address questions about character evolution (where, when and how the character states arose). Because of this second application, molecular phylogenetics has a major impact on many aspects of systematics, evolution, genetics and ecology (Sytsma 1990). There are numerous problems with the biosystematics of many forest tree species. Some such problems and use of biochemical and molecular genetic markers have been reviewed by Strauss et al. (1992). They concluded that, though expensive, by providing a great number of polymorphisms for infraspecific analysis, and highly conserved gene sequences for analysis at interspecific level, molecular techniques promise to provide an excellent opportunity to understand biosystematic relationships at all levels of biological organization.

Although molecular techniques offer unique possibilities, it is important to be cautious. The classical taxonomic treatments are based on comparison of many morphological characters. Chromosome pairing in polyploid hybrids also represents comparison of synaptic ability of many, if not all, Mendeiian loci on the genome. Other techniques, such as measurements of DNA content, DNA hybridization, arm ratios, differential staining, electrophoresis, immunochemical reactions and RFLP studies, allow comparisons involving smaller amounts of total DNA present. All these techniques allow measurements of the similarity of the DNA of the species being compared. The reliability of the technique is directly related to the proportion of the DNA compared (Kimber and Yen 1990). Additionally, uniparental inheritance of character, such as the chloroplast DNA (cpDNA) restriction analysis, makes molecular techniques very precise in comparing DNA similarities. However, uniparental inheritance of cpDNA is not fully substantiated. Harris and Ingram (1991) examined the assumption of low levels of infraspecific cpDNA variation and concluded that far from being rare, infraspecific cpDNA variation was relatively common. Parental inheritance of cpDNA may be common in pines and some other plant species (Dong and Wagner 1994). Recent studies in rice also indicate occasional paternal inheritance and recombination of cpDNA (Dally and Second 1990). So use of cpDNA analysis should be made along with a wider consideration of the degree of intra-individual and infraspecific variation and the mode of plastid transmission. So it will be important to know more on the degree of intra-individual and infraspecific cpDNA variation in natural populations, as well as the effect and influence of a slow 'leakage' of parental plastid DNA on an essentially maternal cpDNA phylogeny. The effects of plastid dynamics within and between populations of cpDNA variability and the extent of recombination between cpDNA in wild plants also should be known. Information on these lines will make the use of molecular techniques for studies on biosystematic and evolution of plant species much more precise.

identification

Production of materials such as descriptors and taxonomic keys for field identification are dependent on a sound taxonomic system and a reasonable knowledge of the distribution of different species. Field guides for bamboos in two Himalayan countries have recently been produced (Stapleton 1994c, d). The format provides illustrations of culm sheaths and leaf sheaths in a consistent manner to allow easy comparison. It is hoped that similar guides will be produced for bamboos of other areas. Identification of difficult plants can often be undertaken more effectively on computer, using multiple-entry keys or more sophisticated systems. These allow for maximum use to be made when only incomplete information on the plant is available (for example, when only the leaves are available) or when the plants are similar and a full identification is not possible. They also allow the use of more illustrations than is feasible in a printed book and can provide assistance on the meaning of technical terms. In plants such as bamboos, which have few characters and can vary greatly within a single species or even a single plant, computer-based systems could provide more reliable identification and complement other methods of identification. However, this is only possible after the bamboos have been thoroughly studied, documented and properly named.

Genetic Diversity and Biodiversity

Biological diversity means different things to different people. In the present context, we can define it to be made up of all species of plants and animals, their genetic material, and the ecosystems in which they occur. We can look at three levels of biological diversity:

1. Genetic diversity: It refers to the variation in genes and genotypes between and within species. It is the sum of variation in genetic information contained in the genes of individual plants, animals and microorganisms. Diversity within the species permits an organism to adapt to changes in environment, climate or cultural methods, or to the presence of biotic and abiotic stresses. Thus, genetic diversity has great evolutionary significance.
2. Species diversity: The term refers to the variety of species within a given area, i.e. species richness.
3. Ecosystem diversity: This refers to independent communities of species and their physical environment. A single ecosystem may cover just a few or thousands of hectares, with characteristic assemblages of plants and animals.

It must be recognized that only diversity can allow sustainability. Only diversity can support social and economic systems to flourish that allow the poorest to meet their food and nutritional needs, and maintain the cultural diversity of countries of the world (Shiva 1994). The biological resources of each country are important, though not all are equally endowed. In general, it is well known that a few countries lying within the tropics and subtropics account for a very high percentage of the world's biodiversity.

As we can see, biodiversity concepts extend beyond simple taxonomic diversity, which is usually expressed as a checklist of species. Variation in and within the species, in ecological habitat, reproductive biology and biomass productivity, and the variety of products obtained from them can all be incorporated to give a broader expression of botanical wealth. Gathering such information would be difficult until the basic taxonomy has been completed, and effective checklists and identification systems produced. On the other hand, it is not possible to postpone the actions required for biodiversity/genetic diversity conservation till all the species are described. So some interim arrangements have to be made and studies on these aspects simultaneously undertaken. It may be appropriate to look at what *role* plant systematics may play in different areas: providing a basis for classification and nomenclature; contribution to traditional plant breeding; contribution to germplasm collection, preservation, documentation and analysis; crop diversification and search for new foods; ornamental, medicinal and industrially useful plants; agricultural use of natural stands; contribution to the control of weeds, poisonous and allergenic plants, and plant pathogens; contribution of plant systematics for ecological agriculture, floristic biodiversity, molecular techniques and genetic engineering; and contribution to legal forensic aspects of agriculture. In these days of diminishing recognition of taxonomists, it is essential that systematics retain their fundamental orientation to the clarification and cataloguing of biological diversity; emphasis on the useful roles played and products produced is both an economic necessity and a social responsibility (Small 1993).

The taxonomy of the great majority of tropical plant species is descriptively based, and little attention has been paid to understanding evolutionary relationships. An understanding of such relationships would allow for better use of existing diversity. Bamboo has over 1 300 congenerics; collecting and assessing all of these is almost impossible. Targeted collections cannot proceed on a sound footing until the phylogeny of the group is better understood (Jar-vie and Bremawie 1992).

Conservation of Bamboo Genetic Resources

As we are aware, the natural resources of bamboo are diminishing day by day. There are a number of reasons for this trend. Some of the more common reasons are cited by McNeely elsewhere in this publication. The paper also covers the approaches to and conceptual basis for conservation, mainly for *in situ* conservation and management of extant stands. Here, it will be appropriate to examine a little more closely the practical method of conservation.

There are two approaches to conservation of PGR: *exsitu* and *in situ.* It is important to emphasize that these two approaches are not mutually exclusive, but are indeed complementary. The work of conserving a gene pool should employ a combination of methods, from nature reserves to gene banks. The appropriate strategy and the balance depends on factors such as the biological characteristics of the gene pool, infrastructure and human resources, as well as the number of accessions in a given collection and the geographic site of the collection. For any given gene pool, the extent of a particular method used may defer from another gene pool. This principle applies to bamboos as well. There is a need to strike a balance between methods used.

Ex situ conservation of seeds

It is well known that under cool and dry conditions, seeds are viable for long periods. Seed longevity is, to some extent, directly proportional to the storage temperature, humidity and seed moisture content. If seeds are maintained under such conditions, the life processes in seeds are minimized so that they could be stored for a number of years with little loss in genetic diversity, genetic integrity and viability. So, it will not be necessary to re-generate them at frequent intervals (Ellis et al. 1985a, b). Nevertheless, because of the conditions under which most gene banks operate, there is a need for periodic regeneration of accessions and restocking of seed in cold store. This is either due to loss in seed viability or depletion of seed stocks because of use and distribution. Critical levels for both viability and quantity are established for each gene bank or species, and when that level is reached seed samples of such accessions are regenerated by planting under optimum agronomic conditions. At every regeneration, there will be some change in the genetic structure of the accession. But it is important to take all the necessary steps to minimize any change in genetic structure that may be caused by genetic drift, genetic shift, selection or outcrossing, or through human error. Good overviews of the problems encountered during multiplication of germplasm are given by Breese (1989) and Rao (1991).

In most bamboo species, the seeds (i.e. fruit, caryopsis) are small and resemble rice or wheat grain. The seed structure conforms to the pattern known for other grasses, with the large fleshy fruit of species belonging to *Melocanna* being an exception. There is hardly any publication providing information on the development and structure of bamboo seeds. Since seeds are produced so infrequently, the percentage of seed viability, germination and other details are also not well studied. Seed sizes are fairly well recorded for certain species (Tewari 1992; Banik 1994).

As opposed to seeds of most common species (called 'orthodox' seeds) that can be dried to very low levels of seed moisture content (below 7%), there are a number of species whose seeds cannot be dried to low levels for optimum storage (Soderstrom 1981; Wong 1981; Anan 1987). Such seeds can be referred to as 'recalcitrant' (Roberts and King 1986; Chin and Pritchard 1988). For long-term storage of such seeds, imbibed storage (seeds maintained at higher levels of seed moisture content) may be of considerable importance. Efforts are also under way to understand the genetic basis of recalcitrance (Shirata 1994). Storage at very low temperatures using liquid nitrogen (cryopreservation) is promising since it considerably extends the seed's life span. Cryopreservation, by both slow and rapid cooling methods followed by slow thawing, of isolated zygotic embryos and whole seeds of cassava showed about 97% of survival rates (Marin et al. 1990). Another area in which much progress has been made is in the storage of ultra dry seeds (dried to seed moisture content of 2-5%) at room temperature conditions. Much is expected also from the in *vitro* conservation efforts that are being made.

Ex situ conservation of plants or tissues

Several techniques have recently been developed to conserve vegetatively propagated species and some of them are undergoing rigorous testing (Jarret and Florkowski 1990; Withers 1993; Rao and Riley 1994). Some promising approaches are discussed here.

Field gene banks/Ex situ conservation stands

There are a number of important plant species,' including staple food crops, fruit trees and forest trees, which are difficult or impossible to propagate by seed and cannot be conserved as seeds. Generally, these are conserved in field gene banks. Another group of plant species that are conserved in gene banks are those with recalcitrant seeds, as mentioned earlier. A number of tropical fruit tree species such as avocado, cacao, coconut, jackfruit and mango – and a number of forest tree species produce recalcitrant seeds, presenting tremendous problems for conservation of genetic diversity in these species. Although field gene banks provide easy and ready access to conserved material for research as well for use, they run the risk of being destroyed by natural calamities and disease. Field gene banks also require more space, labour and may be expensive to maintain (Jarret and Florkowski 1990).

There are many bambusetums established in various countries, usually connected with forest department activities or botanical gardens. Centres of origin and diversity are not known for many of the bamboo species thus collected. Usually the plants grown in the neighbourhood, or propagules brought from other gardens or from wild populations are grown together in bambusetum. Plants in such collections are not well identified with parentage or genetic relationships. At best the ex *situ* stands are only representatives of species collections. Some of the well-known examples in several botanical gardens are just species collections represented by a few clumps, and they do not represent much of genetic diversity either (Tewari 1992). The source materials used to establish bamboo plantations or collections in the homestead gardens also represent a very narrow genetic resource base; but in most cases, the original sources are hardly known or recorded. More well-planned activities are needed in this area of research.

Tissue culture and other alternative techniques

Possibilities now exist to conserve PGR as tissue cultures. For some species, the in vitro conservation may be the only option available. Though tissue culture technology has the potential for germplasm conservation of many plants, there are still a few problems that need to be solved: (1) the genetic instability of the material conserved as tissue culture because of the somaclonal variation at the time of regeneration of the tissue into seedlings; (2) the storage time for tissue is limited. Significant work is being done on both aspects and for some species, tissue culture maintenance is quite feasible since improved techniques offer low levels of somaclonal variation. Work on cryopreservation of tissue culture to lengthen the preservation is also making rapid progress. Once these techniques are refined through further research and development, large-scale adoption will be possible, and PGR conservation could become very cost-effective (Rae 1991; Withers 1993).

For the purpose of PGR conservation, the growth of cultures should be kept to the minimum, if not completely arrested. This is essential to avoid frequent transfer to fresh media, which would require high levels of inputs and will make in vitro conservation expensive. Regeneration and successful propagation of genetically stable seedlings from cultures is a prerequisite in any in uitroconservation effort. Extensive work has been done and protocols for clonal multiplication are well established for several species. Nevertheless, more work needs to be done. Similarly, methods of propagation have to be carefully devised to minimize somaclonal variation, which results in genetic instability as well as loss of genetic integrity of material conserved, for example Musa spp. (Rao and Riley 1994). While establishing large-scale production areas using rapid multiplication and clonal propagation, care should be taken to distribute sufficiently diverse material to the users to overcome the danger-of genetic vulnerability.

In vitro culture methods have so far been used to propagate 73 bamboo species of 20 genera. They include most of the priority species (Zamora 1994). Complete plantlets have been obtained for many of them; for *example, Bambusa bambos, Dendrocatamus strictus, Gigantochloa apus, Phylltostacbys pubescens* and Thyrsostuchys *oliverii.* Rooting was poor in certain other species. Attempts were made to produce artificial seeds in some species such as D. strictus(Saxena and Dhawan 1994). No cryopreservation studies have been conducted so far. Slow growth studies have been completed on certain bamboos, including D. *strictus, B. ventricosa, Schizostachyum brachycladum* and T. *siamensis* (Dekkers 1994). Although in vitro techniques may have many advantages over field gene banks in the case of annual species (Jarret and Florkowski 1990), for perennial species much more research is required.

Cryopreservation

Theoretically, cryopreservation (either by immersion or in vapour phase) is ideal for long-term storage since it virtually suspends all the metabolic activities in any living tissue, be it seed, embryo, cell suspension, callus, cultured tissue, pollen or a shoot tip. Research on development of protocols for cryopreservation of in vitro plant material started in the early 1970s (Withers I990), almost at the same time as experiments for cryopreservation of seed were initiated (Bass and Stanwood 1978; Stanwood 1980). However, there is need to gather data on a long-term basis to confirm the results. IPGRI has been supporting some work along these lines on root crop species, as well as on the cryopreservation of somatic embryos of Musa. By 1991, cryopreservation of somatic, pollinic and zygotic embryos has also been successfully carried out in some 12 species (Charrier et al. 1991), and by now, more number of species must have been added to this list. Work on the cryopreservation of nuclear and somatic embryos of mango is in progress in the University of Florida with IPGRI's support. Restriction fragment length polymorphisms (RFLPs) and random amplified polymorphic DNAs (RAPDs) may be used to monitor genetic stability of cryopreserved material (Tanksley et al. 1989). All the analyses performed so far using phenotypic, isozyme and molecular techniques have not indicated any genetic changes in cryopreserved material in comparison with the control; however, the number of tests and the length of time are not sufficient to conclude and recommend this method on a large scale. This is another area which requires further research.

Another promising method for the conservation of species that are clonally propagated or species with recalcitrant seed is the possibility of producing the so-called 'synthetic' or 'artificial' seeds and conserving them as true seeds. This involves encapsulation of shoot tips and somatic embryos in a semi-solid material which serves as artificial seed coat and endosperm (Senaratna and McKersey 1989). If the current pace of development in this technology continues, and reproducible and widely adaptable results are achieved, production and storage of artificial seeds could become an extremely important technology in PGR conservation and use (Senaratna and McKersey 1989; Dereuddre et al. 1990; Withers 1993). Redenbaugh (1993) has reviewed the latest developments with respect to synthetic seeds, including new methods for the encapsulation of somatic embryos and the creation of synthetic endosperm. This is another area that will require work in the future.

Once the *in vitro* conservation technology is established, a management schedule will be necessary for what may be called as *in vitrogene* banks. The progress in the field of genetic engineering has led to the establishment of DNA libraries, containing single useful genes for breeding programs. Suggestions have been made to store total genomic information of germplasm in the form of DNA libraries (Benford 1992; Jung et al. 1992; Matlick et al. 1992). Despite the current problems, the rapid progress in the subject area may make the storage of DNA an additional option for PGR conservation. Such readily-available genetic resources (without going through the process of collecting, extracting, etc.) will be an added advantage for scientists working at the molecular level. The technique may also allow the recovery of genes from apparently extinct taxa by using herbarium and other non-viable materials, as demonstrated by the sequencing of DNA of fossils (Engels 1993). DNA banking may be one of the areas that would require some attention for problem groups such as bamboos.

In situ conservation

In *situ* conservation involves conservation of diversity in natural habitats where the plant species evolved or occur. 1n *situ* conservation can be carried out either in nature or on farm, depending on the material under consideration. This type of conservation is dynamic as opposed to the semistatic nature of *exsitu* conservation, and provides the species or populations an opportunity to evolve under natural conditions. Furthermore, in *situ* conservation is the only option for some forms of biodiversity. One of the main reasons given for choosing *in situ* conservation over ex *situ* is the need to maintain the evolutionary potential of species and populations. This is not only from the plant breeder's perspective, but also from the conservation biologist's concern for maintaining the variability in small populations and endangered species. Three general research strategies that are needed for in *situ* conservation are:

- Assay genetic variation represented in specific areas to document its relationship to overall patterns of geographic variation (e.g. studies of isozyme or DNA-restriction site variation) within and among populations;
- Conduct genealogical studies (reciprocal transplant studies or progeny tests) to compare performance of native-site-derived material within and among seed zones; and
- Emphasize further study of the special features of genetic variation that have been revealed by either previous research or experience with managed populations or plantations.

From the above, it follows that for successful operation of any *in situ* conservation program we also need information on the following genetic aspects:

1) Studies on genetic erosion resulting from the introduction of new varieties;
2) Identification of regions rich in genetic diversity;
3) Effects of land fragmentation on genetic diversity;
4) Temporal and spatial changes in the genetic structure of populations;
5) Bio-geographic studies, especially when introgression is involved;
6) Minimum viable populations sizes and areas; and
7) Effects of inbreeding and seed banks.

Since most bamboos in South and Southeast Asia are managed stands, information on the effects of growers' practices, cultural preferences and environmental factors also become important. There is also a need to monitor changes that occur in gene frequencies, and the use of molecular markers will be very appropriate. However, in the case of bamboos, there is a long way to go in this direction. Some work currently in progress in INBAR/IPGRI projects is designed to provide information on the distribution of genetic diversity in bamboos. Such information will be useful to identify areas rich in genetic diversity and to assist national programs in designating the areas for conservation.

National forestry activities, of which bamboo is often a component, often focus on the extraction of timber or forest products from forested areas. In contrast, conservation plans for these areas may focus on species inventories and efforts to exclude people from using these resources. Such conservation may not be very effective. Instead, management by local communities can be developed to effectively link conservation and use (McNeely 1994). It is important to consider indigenous knowledge, and participation between local people, researcher and conservationist. Equally important is the'establishment of areas for intensive management or high yielding plantations in order to remove the pressure of overuse of the resources in other protected areas, where systems of community conservation and management are being developed. Conservation activities by commercial forestry users may be fostered since this group derive long-term benefit from such activities, and has the capacity to fund such activities. This can lead to the much-wanted linkage between the public, the community and the private sector in PGR conservation (Riley and Rao 1995).

There are many linkages that can be forged between various institutions and groups in the area of conservation. Formal sector organizations, government agencies, university, non-government organizations (NGOs) and the private sector (including the commercial sector) will need to be involved to link the on-site management and knowledge with research, development and conservation programs in the formal sector. Both *in situ* and *exsitu* conservation can benefit through such linkages.

Summary and Conclusions

The taxonomy of bamboo is highly complex and there is much that needs to be done. Use of modern taxonomic methods, including molecular phylogenetic techniques, may be necessary to hasten up the studies on bamboo taxonomy. It is also recognized that, despite the need for proper taxonomic delineation of bamboos for gathering most other associated data, there is an urgent need to focus attention on issues relating to biodiversity and genetic diversity in bamboos. This is mainly because of the increasing rate of extraction of bamboos and the consequent genetic erosion as well as outright loss of the resources. As we have seen, the biodiversity concept extends beyond simple taxonomic diversity. However, even to recognize the extant variation, some sort of field identification guidelines or a list of descriptors are necessary. Although empirical evidence for the enormous diversity is assumed to exist in bamboos, the details are not available as yet. This may be because, on the one hand, overexploitation is threatening the very existence of the resources and, on the other, conservation of at least a part of the gene pool has become very urgent.

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Abstract

This paper highlights the possibilities and future trends in molecular markers and their possible application in bamboo. The more important application, at present, is undoubtedly the precise identification of bamboo genotypes and the assessment of genetic variation within species. The different molecular markers and the techniques involved in their use are discussed in detail. The advantages of using molecular markers such as genetic mapping and identification are also described.

introduction

Molecular markers are being increasingly used in all fields of biology. They can be of different nature: the genetic material (DNA), primary gene products (RNA and enzymes) or several types of secondary metabolites. In bamboo, where the basic biology is so little understood, the implementation of molecular markers will be a landmark. While isozymes were first applied in bamboo in the early 1970s, the application of molecular markers has been rather limited, both in number of efforts and in scope of applications. It is the purpose of this article to show some interesting possibilities and future trends in molecular markers and their possible application in bamboo.

The possible uses of molecular markers are numerous, ranging from genotype identification ("fingerprinting") to genetic mapping to studies of metabolism. In bamboo, the most important and most practical application at present is undoubtedly the precise identification of bamboo genotypes and the assessment of genetic variation within species. Taxonomists, foresters and others working with bamboos are well-acquainted with the difficulties in identification of bamboogenotypes, and the assessment ofvariation, which in itself is necessary for an efficient selection of superior genotypes. But with molecular markers, a tool is available which, for the first time, allows one to objectively determine the genotype and to assess the genetic variability within species (almost) irrespective of the geographic location or other factors contributing to phenotypic variability. Therefore, although the discussion here is restricted to genotypic identification and the assessment of genetic diversity, other possible applications are also pointed out.

To achieve optimal results, the implementation of molecular markers should be closely associated with more recent developments in the study of bamboo. It should be borne in mind that molecular markers are tools. Unlike model plants *(Arabidopsis,* tobacco) or agriculturally important plants (maize, rice, wheat) which biologists preferentially use, bamboo is a tough subject since little is known about its basic biology, genetics and breeding systems. On the other hand, all foresters should be aware of the possibilities that molecular markers can provide, especially in early assessment of useful genotypes and the identification of useful genetic traits. Molecular markers can also be used to study interesting characteristics, eventually circumventing the problem of flowering and the lack of information on breeding systems.

While considerable progress has been made in recent years in model species and some important agronomic crops, economically less interesting plants like bamboo (which is a misconception since about half the world population uses bamboo and bamboo may become a scarce material) are lagging far behind. This gives us the opportunity to learn from others, and to avoid costly mistakes. While the direct costs for the use of molecular markers are indeed high, real benefits in the genetic improvement of bamboo may also be expected in the long term.

Identification of Genotypes and Assessment of Genetic Variation

Molecular markers rely on differences in DNA structure, gene products or metabolites. Every genotype is characterized by a unique combination of its own DNA, enzymes and metabolites. In nature, a lot of polymorphism is present, even in natural populations. Observing the morphology of bamboo seedling populations will prove this to be certainly true. The seedling populations of *Fargesia murieliae* exhibit a large variation, and the variability in the seedling populations of *Dendrocalawms strictus* has been the subject of a number of studies (McClure 1993).

Variation and polymorphism are necessary to ensure continuous adaptation to changing environments and thus to ensure survival of the species through evolution. But measuring the amount of variability in natural and cultivated seedling populations and, at the same time, selecting useful cultivars or forms is a tedious and time consuming process, requiring careful and long-term observations.

At the molecular level, polymorphism is certainly more numerous and can be detected readily in most species. Since pheriotypic variability is known to be large in bamboo, both within species and among genera and species, we can expect to find it to be highly polymorphic at the molecular level. Polymorphism will be most frequent in DNA itself, and it is known that only a limited number of mutations or other DNA changes can lead to a change in the protein structure.

For the precise identification of genotypes, the resolution of the molecular markers used will be the first criterion of choice. A number of molecular markers are useful for this purpose and these have been put to use: the use of metabolites (flavonoids and volatile compounds), isozymes and DNA has been reported. Much emphasis has been placed recently on the in *situ* and ex *situ* conservation of bamboo to establish bamboo collections with interesting genotypes. Molecular markers can be an efficient tool to avoid duplications in collections, to prevent one from drowning in the genepool and to complement the bamboo knowledge of local people and bamboo specialists. At Oprins Plant, the use of molecular markers was introduced to complement other well-developed techniques as micropropagation and to develop objective tools for genotype identification (Gielis 1995).

Secondary metabolites

Secondary metabolites can be used as chemo-taxonomical markers. Secondary metabolites include terpenoids, alkaloids, and polyphenolics or volatile compounds. Flavonoids in particular are considered as secondary metabolites well suited for “fingerprinting” (Van Sumere et al. 1985). Flavonoids are very heterogenous compounds (over 4 000 different flavonoids have been isolated) involved in a variety of metabolic processes. For an excellent review on flavonoids in grasses, see Harborne and Williams (1987).

Flavonoids and phenolic acids were isolated from leaf material of different bamboos and separated by paper chromatography (Chou et al. 1984a, b). They used 12 taxa of *Bambusa* and seven species of Phyllostclchys. In this study, 39 phenolic compounds including phenolic acids were found in *Phyllostachys,* while 42 spots were found in *Bambusa.* The structure of compounds was not analysed in detail, but the results were combined with isozyme patterns in the same study (see next section). In a later study, *Arthrostylidium, Chimonobambusa* and Dendrocalamus genotypes were used (Chou et al. 1985).

Eighteen bamboo species of different genera were surveyed for flavonoids by Li Shengfeng (1990). The material was the same as used in the study of isozymes (Li Shengfeng 1989; see next section) but two genotypes were added. The main flavonoids found were tricin, apigenin, luteolin and flavone-4-glycoside.

Recently, a study was carried out to refine the techniques for flavonoid extraction and identification (Jia Zhishen et al. 1995). Leaves and branches of bamboos of different ages in 14 genotypes were compared (7 different species of *Phyllostachys,* 2 species of Bambusa and one species of the genera Brachystachyum, Pseudosasa, Pleioblastus, In docalamus and *Semiarundinaria).* The pretreatment and the age of samples were important. Air-dried samples of two-year-old leaves yielded the highest flavonoid concentrations when ethanol and methanol extractions were used.

Thirteen species of *Chimonobambusa* were studied with flavonoids extracted from leaf material. The compounds detected were derivatives of luteolin, tricin and apigenin (C- and 0-glycosides and methylated compounds), quite common in grasses (Lu Shan et al. 1992).

Using gas chromatography, volatile compounds in nine species of *Chimonobambusa* and one species of *Chimonocalamus* were studied. Volatile compounds included fatty acids, terpenes, and aromatic and heterocyclic compounds (Chen and Lu 1994).

Protein polymorphism

Among genotypes, the structure of enzymes with similar function will differ. This will be reflected in a different molecular weight (MW) which can be detected by one-dimensional polyacrylamide gel or starch gel electrophoresis, or by the differences in isoelectric point, which is detected by isoelectricfocusing electrophoresis. The latter type has been used for genotype identification in, for example, potato. The procedure, however, is fairly costly when compared with electrophoresis systems based on the differences in molecular weights of enzymes.

Using polyacrylamide gels or starch gels, native proteins with different MW can be seen when a colouring solution is added to the gel, revealing the presence of native enzymes, the isozymes. Proteins can be denatured by boiling in a denaturant SDS, and fragmented parts of enzymes can be visualized as bands in polyacrylamide gel electrophoresis (PAGE) using Coomassie Blue or silver staining. In bamboo, isozymes have been used in several studies, but SDS-PAGE and isoelectricfocusing have not been used so far.

Starch-gel electrophorksis of peroxidases was used for the identification of bamboo clones of Dendrocalamus latiflorus(Chu et al. 1972) and eight bands of isozymes were found. Using PAGE gels, more than 15 bands of peroxidases were found in D. latiflorus (Chou et al. 1984a). They also tested seven species of Phyllostachys and 11 taxa of Bambusa using peroxidases (Chou et al. 1984a, b), and taxa of *Dendrocalamus, Arthrostylidium* and *Chimonobambusa* (Chou et al. 1985).

Phyllrostachys species were also the subject of another study by Chinese researchers. They tested 14 species of this interesting genus using peroxidases and esterases (Wang et al. 1983). While in the taxonomic revision of *Phyllostachys* (Wang et al. 1980) two groups were distinguished based on a number of morphological features (sect. *Phyllostachys* and sect. Heteroclada wang, C.P. et Ye, G-H.), peroxidase isozymes pointed to three different groups. But peroxidases within the genus were quite stable.

Peroxidases and esterases were used to compare 16 species of eight genera (*Oligostachyum, Pleioblastus, Clavinodum, Bashania, Pseudosasa,* Sass and Indocalamus, as well as Arundinaria gigantea belonging to Arundinarieae (Li Shengfeng 1989). The results indicated that *Oligostachyum, Pleioblustus* and *Bashania* are closely related to *Arundinaria.*
It was also concluded that isozymes are suitable markers to distinguish among species and genera.

Besides peroxidases and esterases, glutamate oxaloacetate transaminase (GOT) has also been used as isozyme system in two studies. Four taxa of bamboo were compared with GOT isozymes (Huang and Murashige 1983), and GOT isozymes were surveyed in the leaves of caespitose bamboos, thus proving it to be a suitable isozyme to distinguish genera and species (Fan et al. 1992).

An isozyme study below species level was performed on *Dendro-calumus asper*. Leaves of D. asper plants were sampled from various populations in Thailand and the varieties showed clear differences in isozyme patterns of peroxidases, while differences in esterases were limited (Boonsermuk et al. 1992).

Isozymes are very useful for the identification of genotypes, certainly at generic and species level. The resolution at infraspecific level may not be sufficient to reveal many differences among genotypes, although this has to be tested. Peroxidases seem to be the best enzyme system with a good degree of polymorphism, with esterases following as a good second.

A major disadvantage is that the enzymatic assays can give different results when plants of different developmental or physiological stages are used. We used leaf blades (foliage leaves) of vegetative shoots of non-flowering plants and leaf blades of foliage leaves proximal to inflorescences of Fargesia murieliae. Differences between flowering and non-flowering plants were observed in peroxidases and shikimic acid dehydrogenase isozymes (Gielis J. and Debergh, P-C., unpublished results). Qualitative differences like changes in shikimate NADP oxydoreductase were also found in relation to lignification of bamboo (Higuchi and Shimada 1967). Nevertheless, the use of isozymes is a relatively cheap and reliable method. But for other applications, the information that can be gathered from isozymes is rather limited.

DNA polymorphism

DNA polymorphism in plant DNA is much more frequent than enzyme polymorphism. While approximately only 3 000-5 000 enzymes are found in plants in total, DNA gives much more chances for polymorphism of several types. For example, the DNA content of *Phyllostachy.* saurea was estimated at 4.6 pg/2C (Bharatan et al. 1994), which means that the genome contains more than 10^9 base pairs. Within the genome, hypervariable regions (tandem repeats) and less variable regions (single copy sequences) are found. More than 95% of the genome does not code for enzymes.

DNA polymorphism can be divided into different classes (Gheysen 1994):

- Base pair polymorphism: deletion or insertion of bases, or changes;
- DNA-sequence reorganizations: deletions, insertions, inversions or duplications of DNA-segments; and
- Expansion-contraction polymorphism: tandem repeats of specific

sequences in the genome can differ considerably in number of repeats and consequently in length.

Another advantage of DNA polymorphism is that it is directly in the genetic material. So every organ or cell can be used and tested at any time, unlike enzymes which are expressed only at certain developmental stages.

In recent years, several assays have been proposed to detect DNA polymorphism and the number is increasing steadily. The methods are based on the use of restriction enzymes which cut the DNA at very specific sites, on the amplification of specific or arbitrary sequences using polymerase chain reaction (PCR), or on a combination of both.

After the DNA is subjected to gel electrophoresis, differences in fragment length are visualized using autoradiography, fluorescence, ethidium bromide or silver staining. The pattern that is produced is called a "fingerprint", and can be simple or very complex. In the former case, the fingerprints can be interpreted by visual inspection but in the latter case scanning of the profiles followed by computer analysis of digitized patterns have to be used.

Methods based on the use of restriction enzymes

The DNA can be cut at very specific sites, using restriction enzymes which naturally occur in the cell that plays an important role in DNA replication. The cut fragments of different genotypes can differ in length because restriction sites in genome A differ from those in genome B. Also, the number of bases in between two restriction sites can differ. This DNA is separated by electrophoresis; but because of the large number of fragments, a continuous smear of DNA fragments occurs throughout the gel.

This DNA is transferred to a nylon membrane using a process called Southem Blotting. This membrane is then hybridized under well-defined conditions with suitable probes and visualized with autoradiography. The probes that are used are sequences cloned from the genome with known or randomsequences. This technique is called restriction fragment length polymorphism (RFLP) and the DNA used can be nuclear DNA or organellar DNA. More detailed information on RFLP can be found in a recent review (Kochert 1994).

In bamboo, both types of DNA have been used in studies of two independent groups. RFLP using nuclear DNA was performed on 37 taxa of bamboo including three species of *Arundinaria* and three unidentified *Arundinaria* sp., B. multiplex and three of its cultivars, 18 species of Phyllostachys with seven cultivars, *Pseudosasa japonica* and one *Sinocalamus* species (Friar and Kochert 1991). The genomic DNA was digested with EcoRV and Hind111 restriction enzymes. The probes were prepared using P. nigra DNA and ten probes were used. A later study (Friar and Kochert 1994) used 20 species of Phyllostachys and three different restriction enzymes. Almost every enzyme/probe combination yielded polymorphism.

In fact, these were the first studies in bamboo using DNA polymorphism. For genotype identification the method was very good, and the results were also used to explore phenetic and phylogenetic relationships in Phyllostacys(Friar and Kochert 1994). One of their major findings was also 'that chloroplast DNA showed much less polymorphism among species with the enzyme/probe combinations they used. Chloroplast DNA (cpDNA) did, however, prove useful to study phylogeny of Asian bamboo genera (Watanabe et al. 1994). They used 16 genera of Asian bamboos including tropical genera *(Bambrua, Dendrocalamus, Gigantochloa, Thyrsostachys, MeloGanna* and *Schizostachyum)* and temperate genera *(Phyllostachys, Pleioblastus, Psetrdosasa, Sinobambusa, Semiarundinaria,* Shibatea and *Yushania).* Fifteen restriction enzymes were used and lots of polymorphism were detected indicating that a suprageneric level cpDNA can be useful to conduct phylogenetic studies. Interestingly, their findings pointed out two major groups of bamboo, one including all temperate genera, and one including all tropical genera.

One of the most interesting developments in molecular markers has been the discovery of mini and microsatellites. In the hypervariable regions of the genome, tandem repeats of specific sequence motifs are found. Microsatellites are repeats of 2-8 base pairs (bp), minisatellites are repeats of longer sequence motifs (16-60 bp). Polymorphism among genotypes results from differences in the length of the tandem repeats, which can be very variable by contraction or expansion of the tandem repeat. This type of polymorphism among genotypes is also called variable number of tandem repeats (VNTR) or simple sequence repeats (SSR) (Akkaya et al. 1992; Morgante and Olivieri 1993). SSR are ubiquitous and highly polymorphic in many plant genomes. Some examples are motifs like TA, TAA and GTGT. VNTR polymorphism can be demonstrated using southern hybridization with oligonucleotide probes complementary to the satellite sequences. VNTR can also be detected using polymerase chain reaction amplification (see next section).

The RFLP technique can yield many fragments, depending on the enzyme/probe combination used. But the technique is also very expensive and time consuming. Another major drawback is the use of radioactively labelled probes, although non-radioactive techniques are available (Kochert 1994).

Methods based on PCR

A major breakthrough in biotechnology was the introduction of polymerase chain reaction (PCR) (Saiki et al. 1985), a principle that had been published already 14 years before (Kleppe et al. 1971; Panet and Khorana 1974). This method is based on an in *uitro* process to duplicate DNA fragments. In a thermocycler, mixtures of sample DNA, primers, nucleotide building blocks, magnesium, buffer solution and a thermostable DNA polymerase are incubated and subjected to several cycles of defined temperatures regimes. First, the sample DNA is denatured at 95°C for a short time, then the temperature is decreased rapidly to 35-55°C which allows primers to anneal to complementary sites in the denatured DNA.

Then temperature is raised to 72°C when DNA polymerization starts. This cycle is repeated (commonly 35 to 50 cycles). The resulting mixture is loaded on a gel and the amplified fragments are visualized by incubation in ethidium bromide and photographed under UV illumination. Silver staining also can be used.

The thermostable DNA polymerases are isolated from thermostable bacteria which thrive very well in hot springs. At high temperatures when enzymes of other organisms are inactivated, DNA polymerases of Thermus *aquaticus* perform well and they withstand repeated exposure to 95%.

Primers used in PCR can be specific or arbitrary. Specific primers based on known sequence are designed to amplify specific genomic fragments, and typically are 20-30 bp in length. Arbitrary primers do not require any prior knowledge on sequence, and primer length is typically 8-10 bp. Because of their short length, the chance to anneal to complementary sequences is fairly high.

Arbitrary PCRprimers. Genotype identification using short single primers was termed Random Amplified Polymorphic DNA (RAPD) (Williams et al. 1990), Arbitrarily Primed PCR (AP-PCR) (Welsh and McClelland 1990), or DNA Amplification Fingerprinting (DAF) (Cdetano-Annoles et al 1991). In RAPD technique, the primers used are 10 bp long, but in DAF shorter primers (8 nucleotides long) are used in combination with a sensitive silver staining of polyacrylamide gels.

PCRproducts result from the amplification of sequences adjacent to primer binding sites on complementary strands. During the first amplification cycles, only some amplification products are selected, and those fragments are subsequently amplified exponentially. Several random or arbitrary primer kits are available on the market or can be made following specific requirements. Polymorphism results mainly from insertions or deletions between primer binding sites. Base changes in the primer binding sites can prevent primers from annealing and the subsequent formation of a PCR product.

Since PCR is a very sensitive method, particular care must be taken to avoid any DNA carry over. With amplification, false positive or false negative bands can occur and distort the results. Calculation methods to avoid distortions have been proposed (Lamboy 1994), but the best method to ensure reproducible results is still the laboratory-dependent fine-tuning of every step in the process.

Identification using RAPD is exemplified by the work performed on the identification of phyllEostachys species and cultivars (Gielis 1995). Phyllostachysis an important genus of temperate bamboos valued in agroforestry and also highly priced as ornamental bamboos in Europe and North America. In all 41 different species and 30 infraspecific genotypes were collected from the excellent collection of Dr J. Vandooren, Belgium.

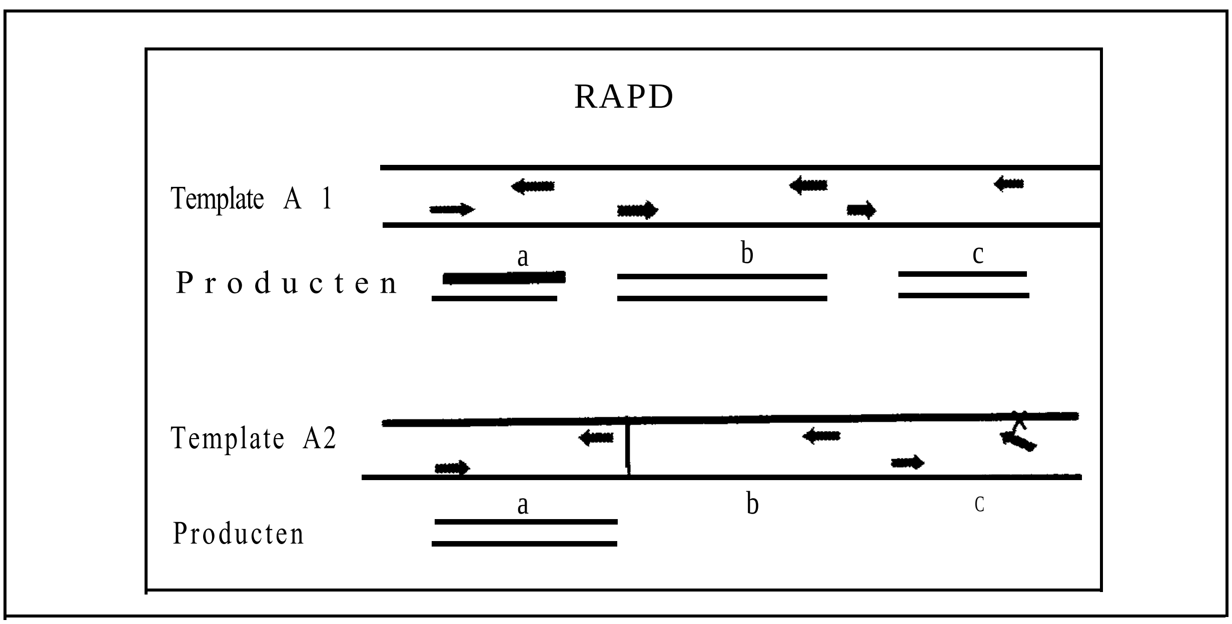


Fig. 1: Molecular identification using RAPD technique (Gheysen 1994)

Much emphasis was placed on ensuring the reliability and reproducibility of the method. Every critical step in the process from DNA isolation to PCR-run, was performed independently by two persons until an optimal reproducibility was achieved.

Sixty primers (Operon kits A, B and C) were tested using four genotypes (P. aureu and cv. Koi, and *P. bambusoides* and cv. Castillonis). From these, seven primers were selected using following criteria:

- clear and distinct bands showing polymorphism among species and cultivars;
- some clear common bands to all genotypes of *Phyllostachys,* to ensure reliability of our method; and
- reproducibility of the bands also in the higher MW zones.

Each *Pbyllostuchys* species tested could be uniquely identified by two or three primers (Figures 2 and 3). We have tested also unidentified *Phyllostachys* and we could also identify misnaming in other collections.

Specific PCRprimers. These primers are designed to amplify only very specific regions of the genome; for example, a particular gene sequence. Sequencing of DNA reads the exact genetic code and contrary to the use of random DNA (RFLP and single primer PCR), even single base pair changes can be detected. This technique is very well suited for detailed phylogenetic studies. Using cpDNA of several grasses and bamboo genotypes, gene sequences of *ndhF* gene (which codes for NADH-dehydrogenase) were amplified in a two-step amplification process and the resulting single-stranded DNA was sequenced (Clark et al. 1995). Genotypes of herbaceous and woody bamboos were compared with grasses from several other subfamilies of Poaceae. Interestingly, in this case also two major groups of woody bamboos were found, temperate and tropical ones and the tropical bamboos resolved in Old World and New World tropical bamboos.

PCR amplification using specific primers was also used in a study of VNTR in rice (Zhao and Kochert 1993). Primers were used to amplify regions with the microsatellite (GGC)n of which about 200 000 copies are present in the rice genome. Within rice, this microsatellite proved to be polymorphic. But interestingly, with these primers the same loci could also be amplified in three bamboos *(Arundinaria amabilis, Phyllostachys rubromarginata* and an unidentified species of *Bambusa;* Zhao and Kochert 1993). VNTR may prove to be very sensitive molecular markers in bamboo.

Combined techniques

RFLP can also occur in amplified fragments. PCR products are then first treated with restriction enzymes, before gel electrophoresis, and this technique is called Cleaved Amplified Polymorphic Sequence (CAPS)

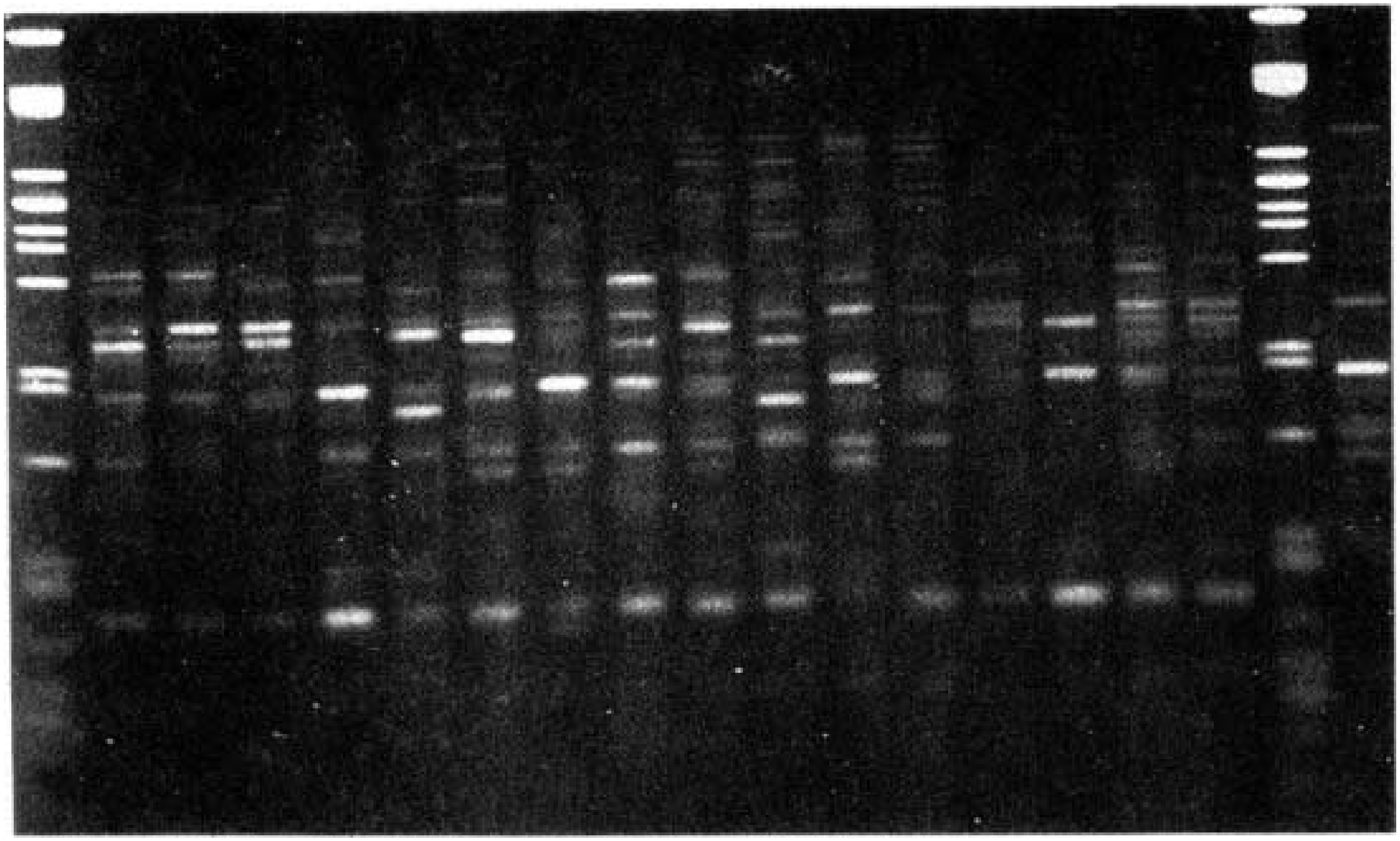


Fig. 2: RAPD patterns of *Phyllostachys* species with Operon B14 primer

Lanes

1	**MW markers**	8	aurita	15	edulis
2	acuta	9	bambusoides	16	elegans
3	angusta	10	bissetii	17	fimbriligula
4	arcana	11	circumpilis	18	**MW markers**
5	atrovaginata	12	concava	19	purpurata
6	aurea	13	decora		
7	aureosulcata	14	dulcis		

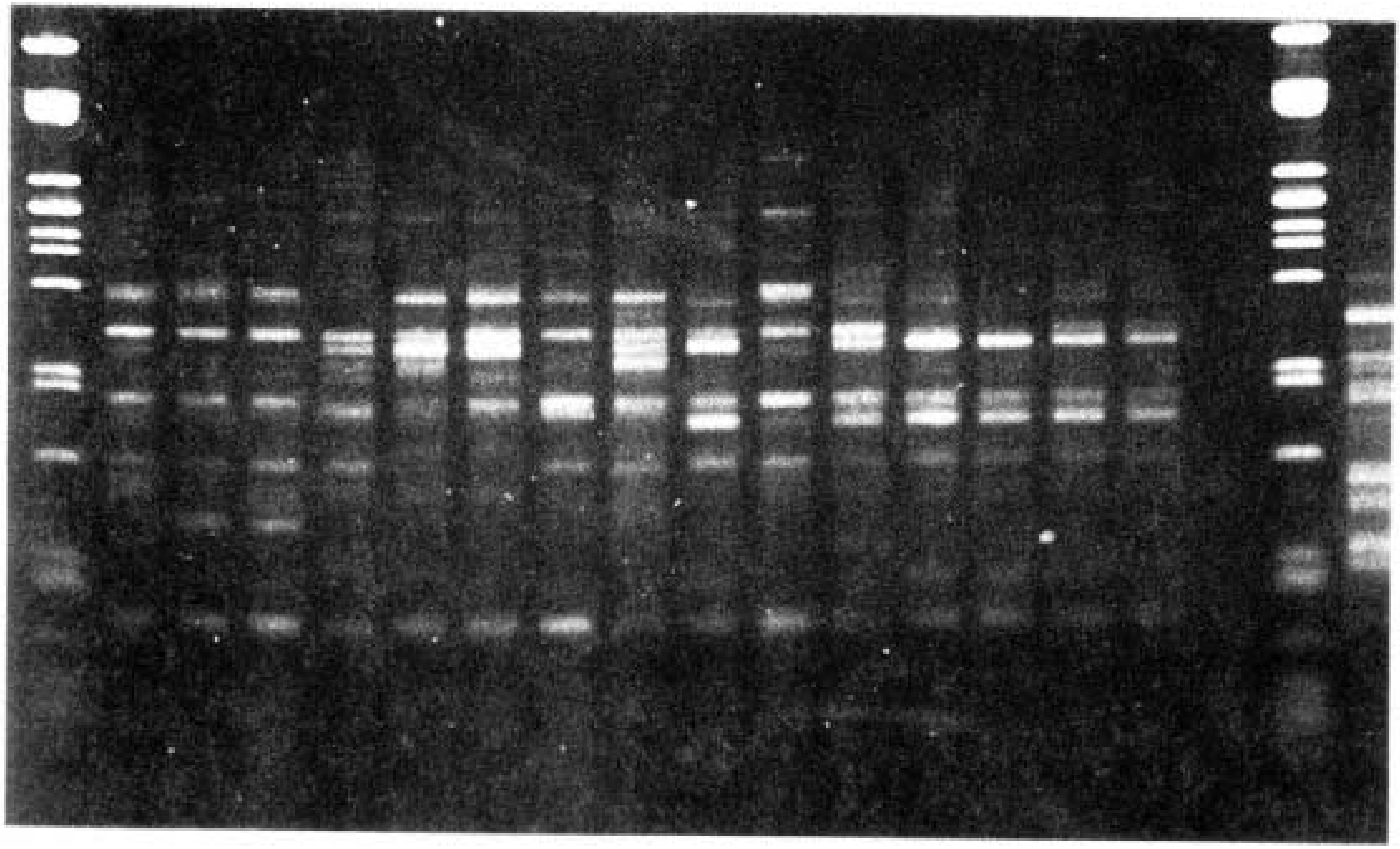


Fig. 3: RAPD patterns of *Phyllostachys* species with Operon B14 primer.

Lanes

1	**MW markers**	7	viridiglauscescens		13	aurea	holocrysa
2	robustiramea	8	viridis	sulfurea	14	aurea	koi
3	rubicunda	9	vivax		15	aurea	takemurai
4	rubromarginata	10	aurea		16	aurea	takemurai
5	stimulosa	11	aurea	albovariegata	17	control	
6	violascens	12	aurea	flavescens-inversa	18	**MWmarkers**	

method (Akopyanz et al. 1992). Unlike RFLP, no blotting or hybridization is needed.

One of the most refined and best methods at this moment is the Selective Restriction Fragment Amplification@ (Zabeau and Vos 1993):Only a limited number of genomic restriction fragments are amplified, using specific restriction enzymes, adaptor oligonucleotide DNA and PCR-primers. The technique allows the detection of alleles in homozygous or heterozygous conditions, and it has a very high resolution.

These techniques use the best of both worlds. A schematic view of the most important assays for DNA polymorphism is shown in Figure 4.

Other Applications

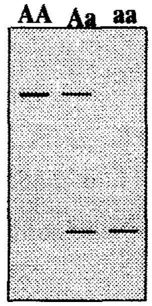
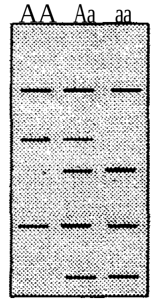
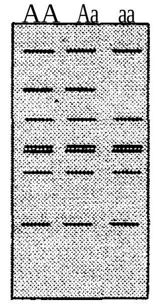
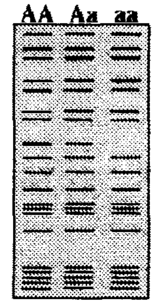
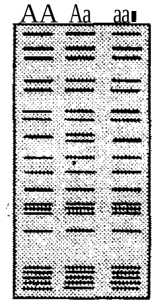
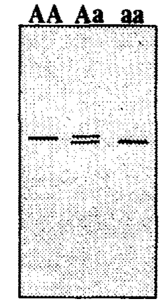
Aid in taxonomy

Possible fields of study

Molecular markers can be useful tools at all caxonomic levels. One of the major advantages is that only leaves are needed, and dried leaves or even herbarium material can be used. This opens new perspectives for bamboo taxonomy. The method which is selected to study relationships among taxa depends on the resolution required. For unravelling relationships among species and genera, random markers (RFLP, single primer PCR and VNTR) are suited. Below the species level, VNTR may prove to be a very sensitive method because repeat DNA evolves very fast; but RAPD also can be a very sensitive method.

At higher taxonomic levels, markers with high resolution are less suited because they yield an overflow of information. To establish relationships between genera or tribes within subfamily Bambusoideae and between subfamilies in Poaceae, marker choice is based on more slowly evolving parts of DNA. CpDNA was used in two independent studies. One used restriction site analysis (Watanabe et al. 1994), while in the other study, part of the ndbF gene (located in the cpDNA) was amplified and sequenced directly, and base mutations were analyzed in detail (Clark et al. 1995).

Based on morphological studies, some genera within the bamboos are presumed to be of hybrid origin. In such cases, molecular markers can aid in the parent identification. Sasaella (Watanabe et al. 1991) and *x Hibanobambusa* are thought to be of hybrid origin. Natural hybrids have also been found in Cbusquea sect. Swallenochloa (Clark et al. 1985). Because of the peculiar flowering of bamboo, natural hybrids are rare. But

Restriction Site Polymorphism		Amplified Polymorphic DNA		Satellite Polymorphism	
RFLP	CAPS	RAPD	SRFTA	Multi locus fingerprint	Single locus fingerprint
Method					
Restriction digest of genomic DNA	Restriction digest of amplified DNA	Amplification with non-specific primers	Amplification of subsets of restriction fragments	Restriction digest of genomic DNA	Restriction digest or amplification
Detection					
Hybridization of blots	EtBr staining of separated DNA fragments	EtBr staining of separated DNA fragments	Autoradio-graphy of radioactively labelled amplified fragments	Hybridization of blots with repeat probes	Hybridization EtBr staining DNA fragment (s)
Polymorphism					
Restriction site	Restriction site	Primer binding site	Primer binding site	Repeat number	Repeat number
Schematic overview of resulting patterns					
 AA Aa aa	 AA Aa aa	 AA Aa aa	 AA Aa aa	 AA Aa aa	 AA Aa aa

Molecular markers allow identification of genotypes, mapping of plant genomes and linkage analysis of interesting traits in plants. At the bottom ofthe figure, simplified resulting patterns are drawn for each method. AA, Aa and aa refer to a single polymorphism at a single locus within a certain genotype. Therefore, the SRFA and multi-locus fingerprints of hybrids derived from two varieties are rather additive as compared to the similarity which is drawn.

Fig. 4: Most important assays for DNA polymorphisms (Depicker et al. 1994)

regional trends of more or less simultaneous flowering of different taxa (Campbell 1985,1987) may be improving natural hybridization. Incompatibility barriers are few in bamboo and outcrossing is relatively easy. Hybrids have been made between, for example, *Phyllostachys* edulis and Bambusa pervariabilis (Zhang and Chen 1985).

Another possible field of study in bamboo taxonomy is the use of molecular markers to delimit genera and species. Generic delimitation is often a big problem. A clear example is seen in *Dendrocalamus, Gigantochloa* and *Bambusa;* which may only be kept apart for historical reasons (Stapleton 1994), and other genera (Sinocalamus, Dendro-*calamopsis,* NeosinocalamzLsand *Sellulocalamus)* have been described for bamboo intermediate between *Dendrocalamus* and *Bambusa.* In a phylogenetic analysis (Watanabe et al. 1994) Dendrocalamus, Gigantochloa and *Bambusa* are grouped closely together.

The status of *Arundinaria* is another example. Some consider only the type species and some related taxa to belong to *Arundinaria;* but over the years approximately 400 binomials have been placed under *Arundinaria.* Some molecular studies show a tendency to interpret genera sensu lato, like Chimonobambusa (Lu et al. 1992; Chen and Lu 1994). But species of *Chimonobambusa* are also available in morphological characters (Stapleton 1994),

The concept of species in bamboo is also a problem. In botany, the use of Biological Species Concept (BSC) was introduced and forcibly argued (Mayr 1992). But the use of BSC is out of the question because for many bamboos the inflorescence is not known. In Fargesia, for example, inflorescences are known only in 17 out of about 75 described species (Orhnberger 1993). In some cases, molecular markers may prove useful for species delimitation. RFLP results (Friar and Kochert 1994) and also RAPD results with *Phyllostachys* show that cultivars and forma are probably closely related species. This should not be too surprising however, since grouping of Phyllostachys has been based largely on horticultural practice in the selection of interesting mutations.

Phenetic and phylogenetic relationships, congruent and incongruent data sets

Traditionally, relationships of taxa in the plant kingdom have been demonstrated with morphological and anatomical markers. Phenetic relationships reflect the degree of morphological similarity of the taxa under study. Distances are calculated with algorithms, and the resulting data (of morphological, anatomical or molecular nature) are clustered by mathematical methods such as UPGMA or Neighbour Joining (NJ). But with the increasing use and resolution of molecular markers and the huge amount of information obtained, also phylogenetic methods, reflecting common lines of descent, are being widely used. Phylogenetic methods are becoming synonymous with cladistic methods. Characters are compared and phylogenetic trees are generated using parsimony analysis (Scott-Ram 1990).

It may be noted that some phenetic clustering methods can, under certain circumstances, also be interpreted as evolutionary relationships. But the distinction between purely phenetic analysis, where all characters are compared, and cladistic analysis, where certain characters are eliminated, is fading because interpretation of molecular markers is no longer possible. Phylogenetic interpretation with molecular data sets is often based on the use of all characters, while rigorous cladistic methodology requires a careful selection of characters. It is clear that molecular markers are very powerful tools, but results should be interpreted only after very careful consideration in taxonomy. At present, it is best to consider phylogenetic trees generated from molecular data sets as hypotheses.

Here, it is pertinent to point out some important remarks of Swofford (cited in Patterson et al. 1993):

1. Consensus trees are simply statements about areas of agreement among trees. They should not be interpreted as phylogenies.
2. In case of apparent incongruence, near-optimal trees can be considered.
3. It is imperative that these studies entail more than a simple comparison of the optimal trees for each. data set.

One of the most interesting findings using molecular markers and phylogenetic analysis was that temperate and tropical bamboos are monophyletic groups. In the study using cpDNA restriction site analysis, this monophyly was supported by high bootstrapping probability (Watanabe et al. 1994), and in the study on ndhF gene sequences also (Clark et al. 1995) two similar groups resolved nicely.

While those two studies agree in this respect (congruent results), one of the major problems with molecular methods is that when using different data sets (for instance, molecular data compared with morphological data) serious incongruence can occur. The most interesting study in bamboo is the placement of bamboo in the grass family (Clark et al. 1995). The placement of some of the herbaceous bamboos in the subfamily

Bambusoideae based on morphological data (Soderstrom and Ellis 1987) is disproved by phylogenetic relationships based on molecular data. At present, the position of genera like *Anomochloa, Steptohaeta* and *Pharus* is uncertain. They are primitive grasses and not very closely related to bamboos phylogenetically (Clark et al. 1995; Clark 1995a).

Another example is *Phyllostachys:* based on morphological characters two sections were found (Wang et al. 1980b), while this was not supported in a study of isozymes (Wang et al. 1980a). Although Friar and Kochert claimed that the sections were supported when using RFLP, this was supported only by relatively weak bootstrapping probabilities, while P. *nigra* apparently grouped in the Heteroclada section (Friar and Kochert 1994). In the taxonomic revision of the genus, P. nigra is placed in section *Phyllostackys* (Wang et al. 1980b); but in the first part of the paper (key), *P. nigra* is listed in both sections (Wang et al. 1980a).

It is clear-that incongruence between data sets is not necessarily restricted to morphological versus molecular matrices, but also: Congruence between molecular phylogenies is as elusive as it is in morphology and as it is between morphology and molecules" (Patterson et al. 1993).

Genetic mapping and identification of useful traits

One of the fields where molecular markers have proved to be very useful is in the construction of genetic maps. This allows breeders to identify indirectly plants with desired genetic traits. In some useful agronomic species, the use of molecular markers has refined genetic maps by several orders of magnitude. The basis for the construction of genetic maps is the measurement of resulting recombination frequency between loci. Random markers as RFLP and RAPD are thought to be distributed throughout the genome and eventually linked to genes of interest, and useful as markers.

Bamboo undoubtedly has some very favourable characteristics that can be used for the genetic improvement, or as a source of useful genes in hybridization between bamboo and rice. Progenies of hybrids between rice and bamboo *(Bambusa textilisas* paternal line) exhibited great variation in a number of characteristics, but all had a strong stalk. By further crossing their favourable characteristics, bamboo and rice may be united in new varieties (Zhang and Ma 1991). Since rice is the major crop in the world, the role of bamboo in future agronomic policy and breeding programs may be even more important than generally assumed.

But because of the lack of valuable breeding systems in bamboo, genetic mapping is very restricted and back-crossing is almost impossible. To our knowledge, nothing along these lines has been done. Some approaches are useful for at least attempting to identify genetic traits in bamboo or to construct genetic maps of bamboo.

- In F_1, F_2 and back-cross population, genetic maps can be constructed using random markers (RFLP and RAPD). Only markers that are heterozygous in one parent and homozygous recessive in the other can be mapped in F,. Seedling populations of different taxa can be used since these can be found throughout the world. However, in most cases, the use of seedling populations in agroforestry practices aims mainly at positive mass selection and inferior genotypes are discarded. To do serious genetic studies, seedling populations should be studied very carefully.
- With random molecular markers, it is also possible to identify useful genetic traits with a technique called Bulked Segregant Analysis (Michelmore et al. 1991). By pooling two different groups, one expressing a specific trait and the other one without the trait, RAPD markers that are linked to the trait of interest can be found. This approach is very useful for the identification of monogenic traits.
- Precocious flowering is a well-known phenomenon in bamboo seedling populations. This behaviour was observed in Bambusa tulda at 18 months in at least five subsequent generations (Banik 1987). This material may be used to find the genetic cause for precocious flowering, leading to an important step in unravelling the flowering process.
- A route which may also be very useful to circumvent the lack of breeding systems is synteny. It has been shown that large portions of the genome are co-linear, even between distantly related taxa. An extensive co-linearity was demonstrated between maize and sorghum (Hulbert et al. 1990; Whitkus et al. 1992) and rice and wheat (Kurata et al. 1994). Plants with less complex genomes (rice with about 0,5 pg DNA/2C) can possibly be used to explore the genome of plants with a more complex genome, like *Phyllostachys aureu(4,4* pg/2C) (Bharatan et al. **1994).**

Conclusion

This paper was focused mainly on molecular markers for genotype identification in the short term, and for fundamental taxonomic and genetic studies on longer term. It is clear that, especially in bamboo, molecular markers can be very valuable in these fields, even in population studies. The molecules used as molecular markers can also be used in numerous metabolic and physiological studies. This subject is not dealt with here, but it is clear that the study of gene expression, enzyme activity and the metabolism of secondary metabolites, can also contribute greatly to the understanding of the basic biology of bamboo.

The current rapid progress in the field is encouraging, although it is expected that molecular markers will find only limited application in bamboo in the near future. While they are useful, the direct costs are very high and results can only be expected in the long run. It is also clear that the selection of useful bamboo genotypes is only in its infancy, and other fields of study in bamboo are also developing at a different pace. It is necessary that these concerns motivate bamboo researchers to a wise and well-considered implementation of molecular markers as tools for complementing other techniques.

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A Mathematical Study on the Distribution of the Endemic Genera of Chinese Bambusoideae

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Abstract

This paper studies the distribution of the endemic genera of Chinese Bambusoideae using mathematical methods. The results showed that the endemic genera of Chinese Bambusoideae originated in the south-western and southern areas of China before the Quaternary period, especially in the south-western areas, and they then developed and dispersed to the central and eastern areas of China to form the distribution pattern and range seen today.

Introduction

Previous studies have described the taxonomy and distribution of the endemic genera of Bambusoideae in China (Zuo 1991a, b, c, 1993a). However, the numbers of the endemic genera of Bambusoideae in China have changed, as recorded by other taxonomic studies (Chao and Chu 1991; Hu 1991; Wen 1992; Yi 1992). This has necessitated a fresh analysis of the distribution of the endemic genera of Chinese Bambusoideae using mathematical methods.

Quantitative Data

Table 1 gives the province-wise distribution of the endemic genera of Bambusoideae in China.

From the table, we can calculate the province-wise floristic abundance (value of comprehensive judgement) of the endemic genera of Chinese Bambusoideae using the comprehensive judgement method in fuzzy mathematics (Zuo 1993b; Zuo et al. 1994). The results, in decreasing order, are as follows: Guangdong (0.1262), Sichuang(0.0838), Guangxi (0.0808),

Table 1: Province-wise distribution of the endemic genera of Chinese Bambusoideae

Province	Tribe	Genera	Species
Guangdong	4	7	15
Yunnan	3	5	8
Hainan	3	5	7
Henan	3	5	6
Hubei	3	5	5
Guangxi	3	4	10
Hunan	2	5	6
Sichuan	2	4	12
Guizhou	2	4	8
Zhejiang	2	4	5
Jiangxi	2	4	4
Shanxi	2	3	3
Gansu	2	3	3
Fujian	1	2	5
Taiwan	1	2	2
Jiangsu	1	1	1
Anhui	1	1	1

Yunnan (0.0796) Hainan (0.0755), Henan(0.071 l), Hubei (0.0667), Guizhou (0.0662) Hunan (0.0654), Zhejiang (0.0558), Jiangxi (0.0514), Shanxi (0.0429, Gansu (0.0425), Fujian (0.0375), Taiwan (0.0257), Jiangsu (0.0181) and Anhui (0.0181). Further analysis with the help of the parametric estimation method (Zuo 1991b) show that the flora of the endemic genera of Chinese Bambusoideae in Guangdong, Sichuan, Guangxi, Yunnan and Hainan are the richest, followed by Henan, Hubei, Guizhou and Hunan. Zhejiang and Jiangxi are poor in flora, while Shanxi, Gansu, Fujian, Taiwan, Jiangsu and Anhui are the poorest. Therefore, Guangdong, Sichuan, Yunnan and Hainan - that is, the southern and the south-western areas in China - appear to be the centres of diversity and development of the endemic genera of Chinese Bambusoideae.

Resemblant Analysis

The provinces given in Table 1 were taken as the operational geographical units or OGU, (Crovello 1981), and the number of species with the endemic genera - X_{IJ} and X_{IK} - were regarded as the attributes of OGU_{JK}

Using the coefficients of Bray-Curtis (1957), the dissimilarity matrix can be calculated and then the results transformed into a similarity matrix (Zuo 1990) as in Table 2.

Following the fuzzy-graph theory (Zuo 1989b), the similarity matrix may be made into a chart (Figure 1). In Figure 1, the provinces have been separated into four geographical groups — South China (Guangdong, Guangxi and Hainan), South-West China (Sichuan, Guizhou and Yunnan), Central China (Hunan, Hubei, Henan, Shanxi and Gansu) and East China (Anhui, Jiangsu, Jiangxi, Zhejiang, Taiwan and Fujian). Combining the affinity of the groups, shown in Figure 2, with the distribution of the endemic genera of Chinese Bambusoideae, the following results are obtained:

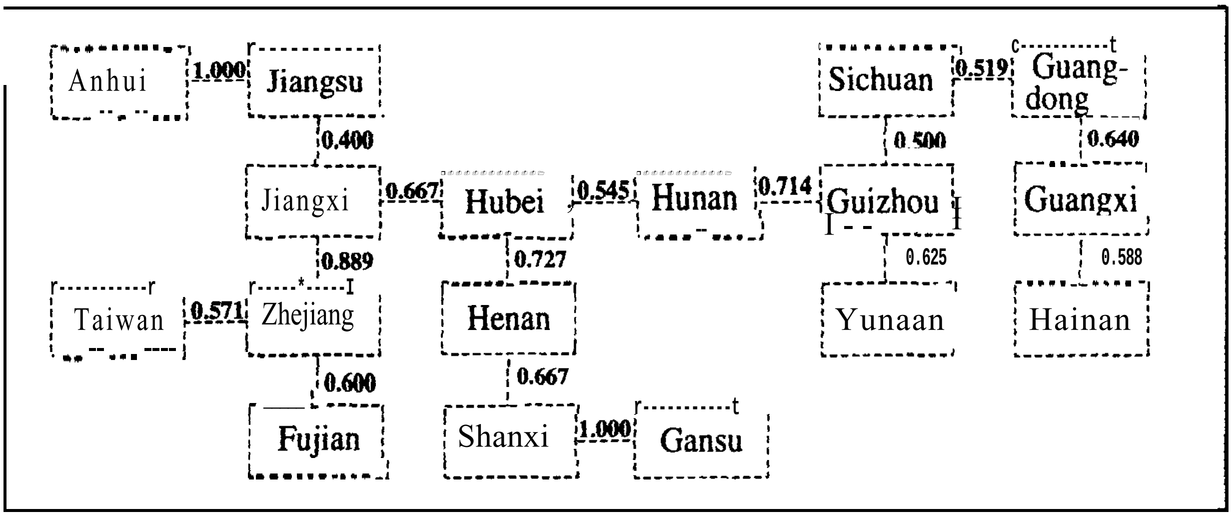

Fig. 1:Relationship of the endemic genera off Chinese Bambusoideae in 17 provinces

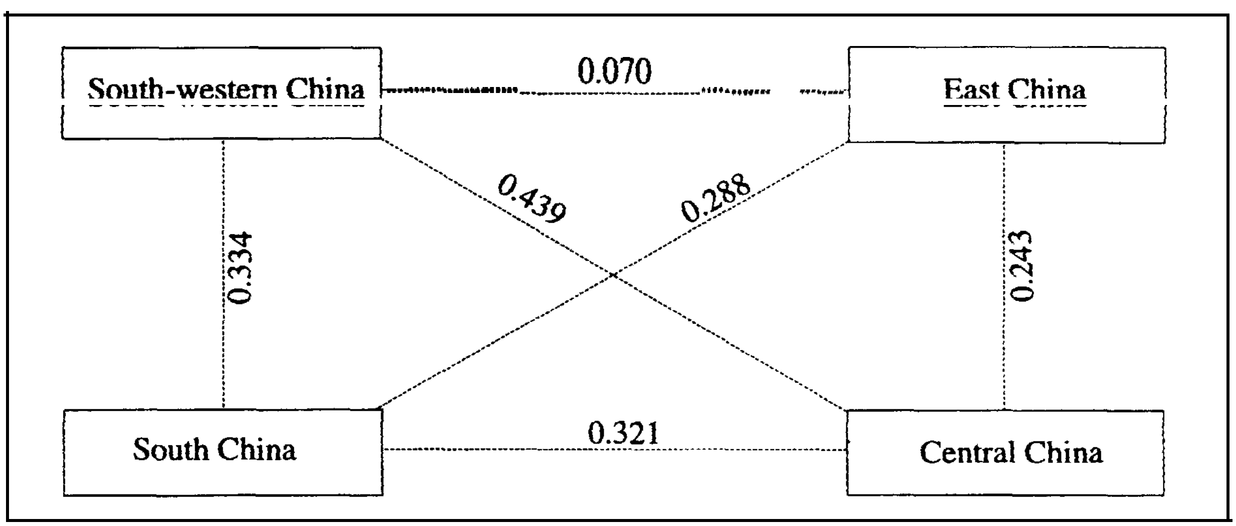

Fig. 2: Affinity of the endemic genera off Chinese Bambusoideae among four geographical groups

Table 2: Similarity coefficients of the endemic genera of the Chinese Bambusoideae between and two provinces (symmetric matrix)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Yunnan	1.000																
Sichuan	0.500	1.000															
Guizhou	0.625	0.500	1.000														
Guangxi	0.222	0.273	0.333	1.000													
Hainan	0.400	0.316	0.333	0.588	1.000												
Guangdong	0.261	0.519	0.348	0.640	0.545	1.000											
Zhejiang	0.000	0.000	0.136	0.400	0.500	0.400	1.000										
Fujian	0.000	0.000	0.000	0.400	0.500	0.400	0.600	1.000									
Taiwan	0.200	0.143	0.400	0.167	0.228	0.233	0.571	0.000	1.000								
Jiangsu	0.000	0.000	0.000	0.000	0.000	0.125	0.333	0.000	0.000	1.000							
Anhui	0.000	0.000	0.000	0.000	0.000	0.125	0.333	0.000	0.000	1.000	1.000						
Jiangxi	0.000	0.000	0.167	0.286	0.364	0.316	0.889	0.444	0.333	0.400	0.400	1.000					
Hunan	0.357	0.333	0.714	0.250	0.308	0.286	0.182	0.000	0.500	0.000	0.000	0.200	1.000				
Hubei	0.308	0.235	0.533	0.400	0.333	0.400	0.600	0.200	0.286	0.333	0.333	0.667	0.545	1.000			
Henan	0.429	0.444	0.429	0.250	0.462	0.381	0.364	0.182	0.250	0.286	0.286	0.400	0.500	0.727	1.000		
Shanxi	0.545	0.400	0.545	0.154	0.400	0.222	0.000	0.000	0.400	0.000	0.000	0.000	0.667	0.500	0.667	1.000	
Gansu	0.545	0.400	0.545	0.154	0.400	0.222	0.000	0.000	0.400	0.000	0.000	0.000	0.667	0.500	0.667	1.000	1.000

- The shared genera of South-West China are Neosinocalamus, Ampelocalamus and *Basbania,* the endemic genera are *Leptocanna, Ferrocalamus* and *Menstruocalamus;*
- The shared genera of South China are *Monocladus, Neosinocalamus* and *Oligostachyum,* while the endemic genera are *Monocladus* and *Metasasa;*
- The shared genera of East China are *Brachystacbyum, Oligostachyum, Clavinodum* and *Gelidocalamus,* and there are no endemic genera in this area;
- The shared genera of Central China are Neosinocalamus, *Ampelocahmus* and *Bashanti,* and *Polyanthus* is the only endemic genus.

According to the results, South-West and South China are the centres of the diversity and development of the endemic genera of Bambusoideae in China.

Discussion

The number of endemic genera (including the number of species) and the original taxa on morphological evolution are less from the eastern and central areas of China, while this is just the opposite for the southern south-western areas of China (Wen 1983; Zuo 1989a, 1991 b). Besides, with regard to the floristic elements of the endemic genera of Chinese Bambusoideae (Zuo 1991a, b, c), they are the most in South-West and South China and the least in Central and East China.

Before the Cretaceous period, the south-western and southern areas of China – which included the three old lands of Kandian, Sichuan and Cathay – adjoined the Tethys and old Pacific Ocean, respectively. These regions are very hot with abundant precipitation. Furthermore, the influence of the Himalayan geological orogeny of the Tertiary period (without the extensive glaciation of the Quaternary period; only the intervallic mountainous glaciation and the cold weather of glaciation are influential) and the complex topography and geomorphy of the land must have intensified the breeding and development of Bambusoideae . So, the southern and south-western regions, especially the latter, appear to be the centres of origin of the endemic genera of Chinese Bambusoideae (Wen 1983; Zuo 1989a, *1991a,* b, c, *1993a)*

The endemic genera, such as *Monocladus, Neosinocalamus, Oligostachyum* and *Clavinodum,* in the Chinese Bambusoideae are distributed between Chinese mainland and Hainan Island, and *Ampelocalamus* and

Geliducalamus between the mainland and Taiwan. The distribution of *Ampeloculamus,* in particular, seems disjointed, covering the Chinese mainland, and Hainan and Taiwan islands. The reason for this could be that before the Tertiary period, Taiwan and Hainan islands belonged to the Cathaysian platform. During the Quatemary period, however, they were alienated from this platform (Zuo 1989b). Therefore, the geological time for the origin of the endemic genera of the Chinese Bambusoideae is the Quaternary period or just before it.

Conclusion

From the discussion above, certain postulations can be made. The endemic genera of the Chinese Bambusoideae originated in the south-western and southern areas, especially the southwestern area, of China before the Quaternary period. They then developed and dispersed to the central and eastern areas of China to form the distribution pattern and range seen today.

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The Flowering of Three Siecies of Thorny Bamboos in Hong Kong: 1993-95

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Abstract

This paper reports on the flowering of three thorny bamboo species — *Bambusa chunii, B.flexuosa* and an unidentified species in Hong Kong during 1993-95. Flowering progression was monitored by observations primarily of bamboo plants in the Kam Tin Valley and some plants in other parts of Hong Kong. Evidence regarding earlier mass flowering cycle was collated and a 50-year flowering cycle was noticed. The report also highlights how the rapid pace of development, as well as the changing attitudes in the Kam Tin Valley and other parts of Hong Kong are threatening bamboo seedlings.

introduction

Gregarious flowering of semelparous, woody bamboos at supra-annual intervals is a well-documented phenomenon in only about 20 of the known species of bamboo (Campbell 1985). Evidence of a fixed periodicity in many other species is at best scanty, and since flowerings cannot be predicted, opportunities for study are necessarily incidental. In 1994, thorny bamboos all over southern China flowered en *masse,* and we were thus very fortunate in being able to study the flowering of *Bambusa chunii, B. flexuosa* and at least one other presently unidentified thorny species in Hong Kong during 1994-95, with preliminary observations in 1993. Flowering phenology and aspects of pollination biology were followed and we also suggest a possible intermast period.

Study Area: Hong Kong

Hong Kong is currently a British dependent territory on the southeastern bank of the Pearl River estuary in southern China. It consists of Hong Kong Island, Lantau Island, a portion of the Chinese mainland (Kowloon and the New Territories), and over 200 other, smaller islands (Dudgeon and Corlett 1994). The highest point, Tai MO Shan in the centre of the New Territories (N.T.), is 958 m above sea level and there are 27 other peaks over 500 m. The Kam Tin valley with Yuen Long in the north-western N.T., the Fanling plain in the northern N.T. and the Kowloon Peninsula are the only non-coastal areas of notable size below 100 m altitude. Hong Kong's climate is highly seasonal and is governed by the monsoons, resulting in a hot and wet "summer" (May-September) and a cool and dry "winter" (November-February). Mean annual rainfall for the period 1961-90 was 2 210 mm, 77% of which fell during the "summer" months. Mean monthly temperatures during the same period ranged from 15.8°C in January to 28°C in July.

Bambusa flexuosa Munro, the "small thorny bamboo" is native to Hong Kong and to China's Guangdong Province, which forms Hong Kong's north-em border. It is widely planted around villages as a thorny screen and to improve feng shui (good.fengshui brings prosperity to a village), but is more naturally found along riverbanks at low altitude. *B. chunii* Chia and Fung, the "woon yung bamboo", is known only from one location in Hong Kong and is so far unrecorded in mainland China. Distinguishing the two species in the vegetative state is relatively straightforward. Culm sheaths of B.flexuosa are sparsely hairy with a triangular horn at each shoulder, and the foliage leaves are glabrous. Culrnsheaths of B. *chunii* are glabrous with a horn on the inner shoulder only, and the foliage leaves have soft hairs on the underside (But et al. 1985; Chia et al. 1983). However, differentiating between themin the flowering state is extremely difficult, as B. *chunii* is known only from sterile specimens and the type plant was destroyed in the late 1980s. Thus, all the positive identifications presented here have been made from sterile material only (by A.J.B.) and the many unidentifiable flowering specimens are being sent to The Royal Botanic Gardens, Kew, for identification. Three other species of thorny bamboos grow in Hong Kong: B. lapidea McClure, B. rutila McClure and B. sinospinosa McClure. But as far as we are aware, none of these were flowering gregariously during this period.

Materials and Methods

Flowering phenology

Occasional observations were begun in spring 1993, when a small percentage (1.5%) were found to be in flower, and continued until the spring of 1994. From this time on, flowering progression was monitored by observations primarily of plants in the Kam Tin valley, but with occasional observations also on as many other plants in Hong Kong as possible.

Pollination biology

The main observations were conducted on plant YLCPR1 (Yuen Long Castle Peak Road No. 1) in Yuen Long during March and April 1995. This plant had produced a small clump of fresh shoots at ground level in 1994, and these began flowering gregariously in early March 1995. Additional observations were made on plant HUT1 (Heung Uk Tsuen No. l), which had been burnt on one side in autumn 1994, and had also produced a large clump of fresh shoots which began flowering in late March 1995. Preliminary identification put both plants as *B.flexuosa.*

As regards the temporal aspects of flower opening, flowering branches were tagged for observation of floret opening times. Stigma receptivity with time was investigated using hydrogen peroxide and by occasional hand-pollination. Timing of anther.dehiscence was measured by observation of the anthers once the maximum filament length had been reached. All measurements were conducted at ambient temperature and relative humidity (28+2°C and 88+5%, respectively) on sunny days.

With regard to pollen germinability tests, the liquid media used did not support the germination. Excellent germination was, however, obtained on semi-solid medium containing 1% agar and 0.2M sucrose (Figure 1). The addition of calcium, as $CaCl_2$ or $CaNO_3$, or boric acid had no significant effect. The hydration of the lower surface of germination media was found to be much more uniform than the upper (Heslop-Harrison 1979). Following Hesiop-Harrison (1979), warmed medium was poured to a depth of 1-2 mm into 90-mm plastic petri dishes. After cooling, the medium was cut into 25 mm square portions on a glass cover slip and these were placed inverted on the upturned lids of 40-mm diameter plastic petri dishes for inoculation. Uncovered media dried out rapidly; so after inoculation, the base of the dish was placed on top of the lids and sealed with Vaseline. Pseudospikelets with fully extended anther filaments were sealed in polythene bags and transported to the laboratory within 90 minutes of collection. Dehisced anthers were kept at ambient temperature and humidity for various periods before sowing. Time for germination was recorded as being when the pollen tube first emerged from the grain. One anther

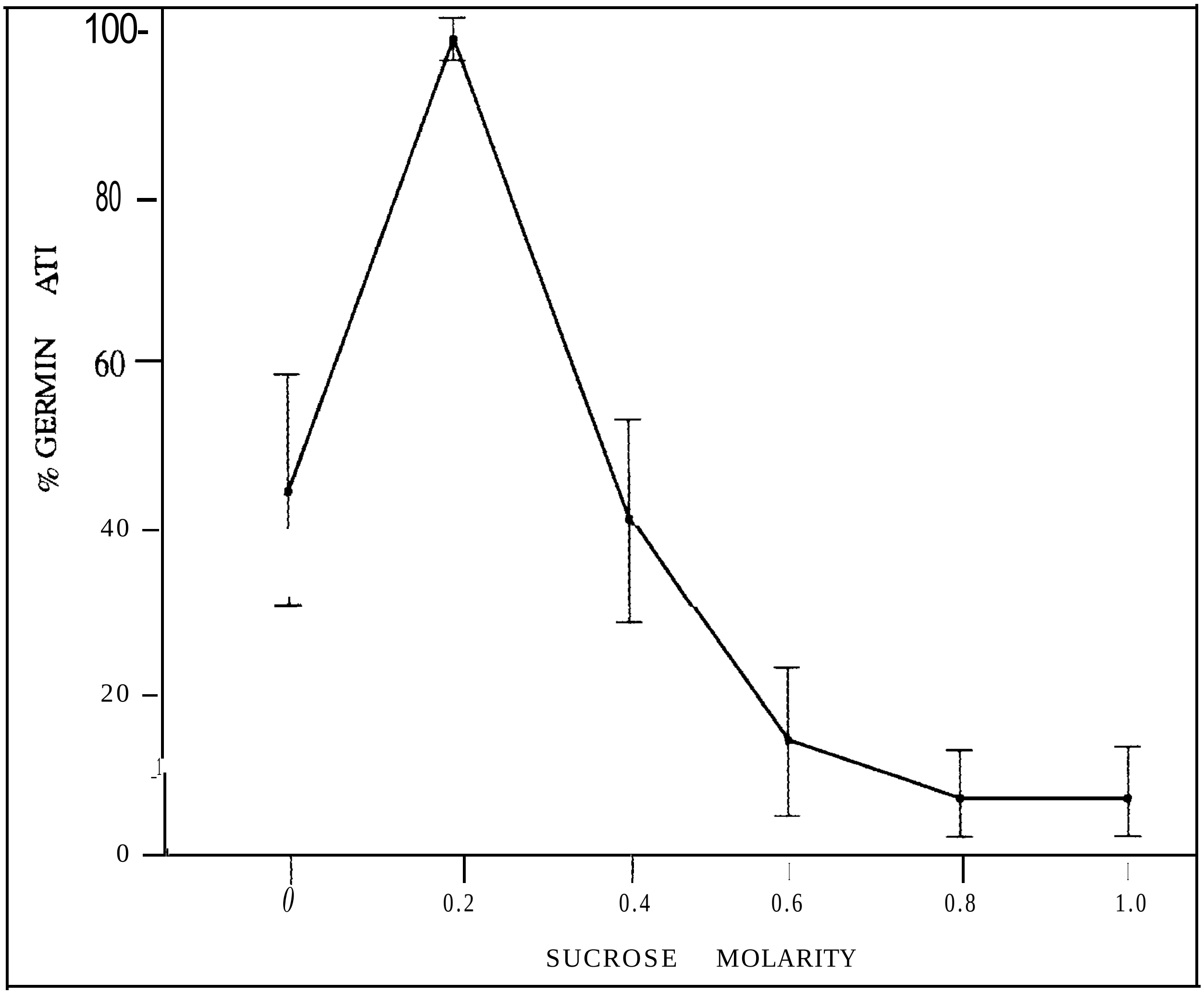

Fig. 1: Effect of sucrose molarity on germination of pollen of *Bambusa flexuosa* (N=3 000)

from each of six pseudospikelets was selected, and 600 grains from each anther used for each measurement. All measurements were made on pollen from anthers collected between 4.30 and 5.30 PM.

Results

A total of 522 individual thorny bamboos were found in flower during 1993-95. All but one are distributed in the northern and western N.T. (Figure 2). Only two plants grew above 100 m altitude; one at the head of the Kam Tin valley and one at Shatin in the central N.T. Only five of the plants collected had sufficiently intact culm sheaths to allow identification and all were identified as B..flexuosa (four in the N.T. and one on Lantau). It is often observed that bamboos preparing to flower do not produce new culms the year before flowering (Anonymous 1974; McClure 1966),

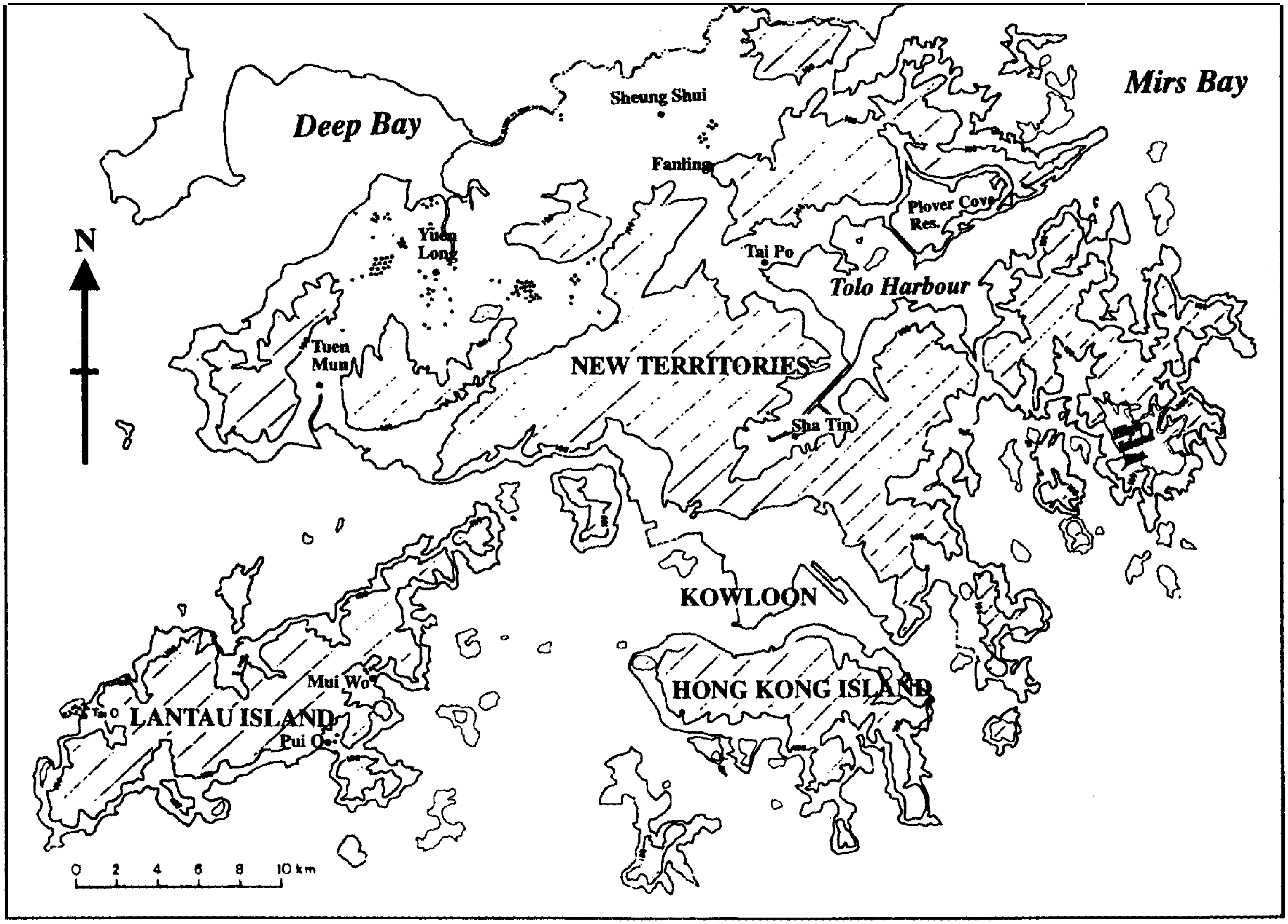

Fig. 2: Areas where thorny bamboos were in flower during 1993-95

and this seems to have been borne out in the present study. One problem was that identification was very difficult in this case since the plants were in flowering (in previous studies on the flowering of Hong Kong's bamboos plants in 1994, identification was made in the vegetative state).

Both But et al. (1985) and McClure (unpublished) state that the thorny bamboos on Lantau are B..flexuosa and that it is widely grown around villages in the NT. Collections during the first-mentioned study also included sterile specimens from one of a group of plants on the side Tai Po Road in Fanling in 1980. The plant was identified as *B.flexuosa*, as represented by the ones growing in the Hong Kong Herbarium. However, aerial photographs taken in 1977 show many more than four plants by the roadside. Even allowing that commercial development since then have caused the demise of the others, we cannot be sure that the herbarium specimen represents one of the plants in flower in 1994. *B. chunii*, on the other hand, was known only from one village in the Kam Tin valley. But in the absence of more reliable identification methods, foliage leaf pubescence had to be used to identify the seedlings of plants in the Kam Tin valley as *B. chunii*.

At least one other thorny bamboo species was found to be in flower in 1994. Two of these plants were growing in the Kam Tin valley, and they were the only ones with albino seedlings (in 1:3 ratio). The culm sheaths closely resembled those of B. tuldoides Munro, but as the plants were thorny this seems unlikely.

Some of the plants in the Kam Tin valley and others in Yuen Long had large witches broom-type growths up to 1.5 m long. They were not seen on these plants in the vegetative state, and such growths have so far been seen only on a few other plants in Hong Kong, including one vegetative B. gibboides and one B. tuldoides. Plants in feng shui woods to the west of Yuen Long and on Lantau, tentatively identified as B.flexuosa, showed no signs of such growth. Witches broom is common on bamboos in China, and a serious infection can kill entire stands (Anonymous 1974). It is caused by the organism Balsania take(Miyake) Hara (Zhu 1989) and is transmitted mechanically (Poon and Kuo 1980), possibly via the guts of sap-sucking insects. One species of these insects (Hemiptera: Fulgoroidea - plant hopper) was collected from the flowers of plants in the Kam Tin valley and now awaits identification. These insects were not seen on uninfected plants, and it is probable that the occurrence of the disease owed more to their distribution than to species susceptibility.

Flowering phenotogy

Seven plants just east of Yuen Long which started flowering, in spring 1993, had died completely by August 1994 and had been dug up and the area covered with concrete by May 1995. Flowering was first followed in the Kam Tin valley in early January 1994 on a number of roadside plants. By mid-February, all these plants had reached a state of 100% flowering (all culms leafless and in full flower). Conversations with local residents in areas not visited at that time indicated the same was true for all the plants in the Kam Tin valley/Yuen Long area and Lantau island. Seed development was not seen at that time.

The first and the only major seed drop occurred in late-April and hence, the seed maturation time was estimated to be about two months. Elderly local residents reckoned that there would be one more mass seed drop in another two or three months and then the plants would die. In fact, no seed drop occurred, although the plants were occasionally seen bearing a few developing seeds until the end of the summer. Many plants continued flowering until September and by November, some had died and most had only one branch left alive. During December, however, many of the remaining live branches apparently reverted to the vegetative state, resuming leaf production from the apices of flowering branches. By March 1995, all were flowering again. Approximately 95% of the plants were dead by July. Observations of other plants in Hong Kong throughout 1994 and 1995 indicate that the same pattern was true for all the plants of the population, except for some to the west of Yuen Long which were still flowering on most branches at the end of November but were dead by March 1995. One plant of the whole population was not in flower in 1993 or 1994, but was in flower by March 1995. Only one plant of the whole population (B.flexuosa) has survived to produce new culms.

Floral biology

Each node of the flowering branches of B.flexuosa studied produced initially up to 15 pseudospikelets, more from the basal nodes. Each pseudospikelet usually contained between 4-7 individual florets. However, if these remained unfertilized, apical growth of the pseudospikelet continued, and reached 22 florets per pseudospikelet in one instance. Floret opening was acropetal. However, in about 25% of pseudospikelets, the basal floret did not subsequently close. Floret opening took approximately two hours for all florets, irrespective of their position on the pseudospikelet, after which time the palea and lemma were at a 40° to 50° angle to each other. Florets generally remained fully opened for a few hours (less than 24 h) before closing again in two hours. Stigmas remained viable throughout the time the floret was open and since all the hand-pollinated florets set seed, this suggests that the plants are self-compatible. Timing of anther dehiscence was variable, but usually took place between 1 and 1.5 hours after the maximum filament length was reached.

Sixty eight percent of the pollen germinated between 1.45 and 2.45 minutes after inoculation (Figure 3) (N = 510). The tapetum of those germinating at this time lifted after about 1.15-1.30 minutes. Loss of viability of pollen after storage at ambient temperature and humidity is shown in Figure 4. Germination of pollen from HUT1 did not differ significantly from that of YLCPRl. All the monitored branches of YLCPRl died after seed

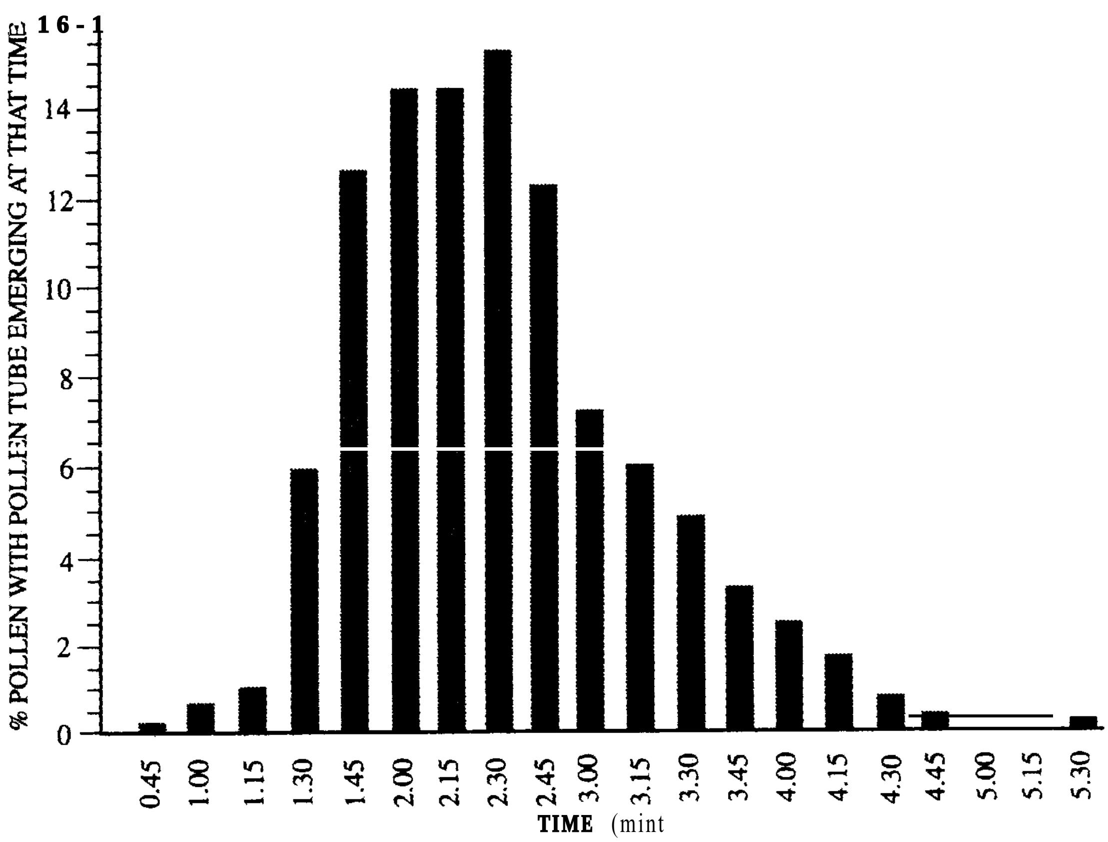

Fig. 3: Germination of pollen after inoculation

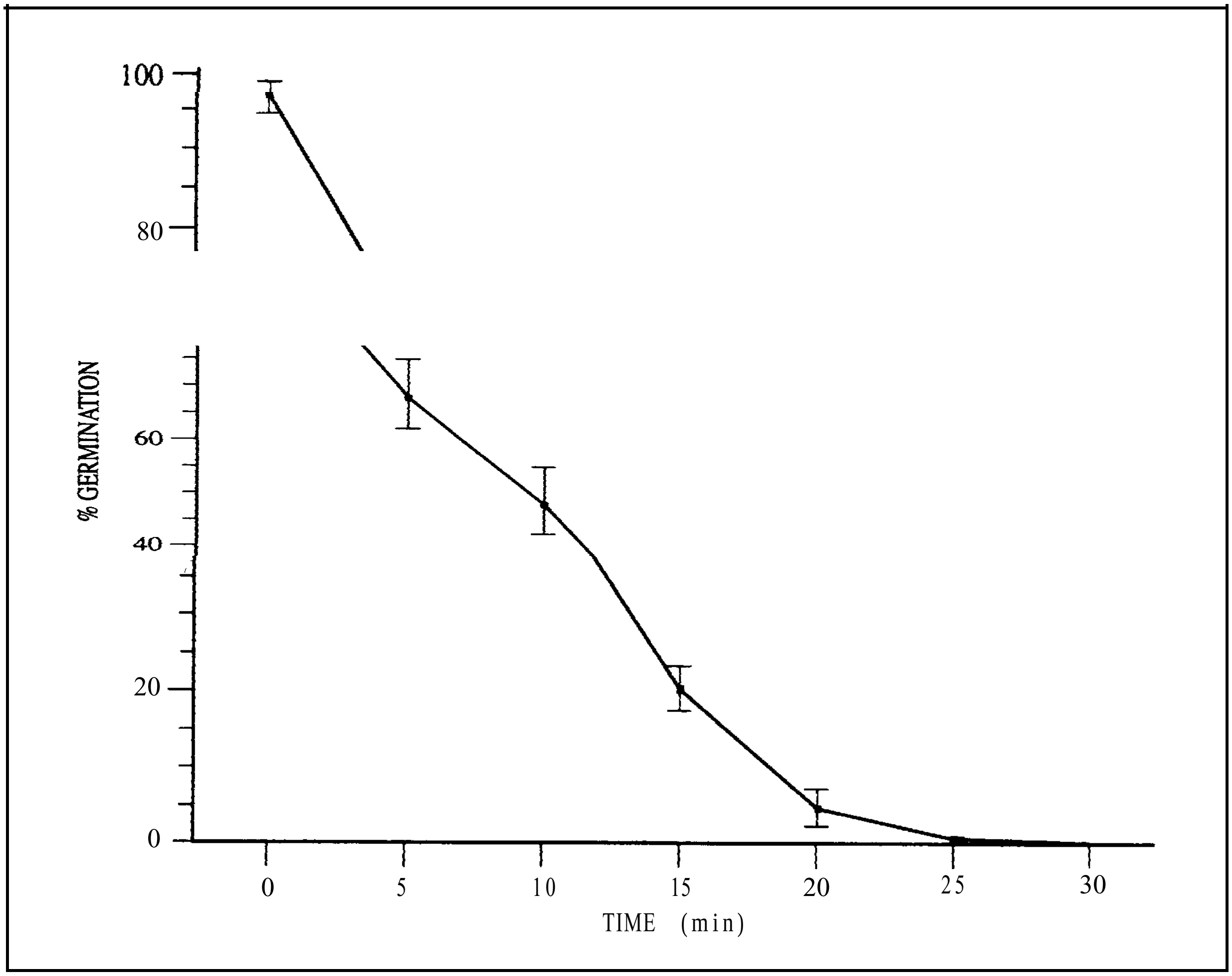

Fig. 4: Loss of pollen viability on storage

setting, but pollen from florets formed after the first seed setting on HUTI was greatly reduced: of approximately ten samples, pollen from only one floret could be germinated (70%). Pollen collected from ten plants in the last throes of flowering in November and December 1994 and March to June 1995 could not be germinated.

Flowering interval

Suggestions of a possible flowering interval in B. chunii and B..flexuosa necessarily draw heavily on anecdotal and photographic evidence. Anecdotal evidence from a number of middle-aged local residents in Kam Tin and Yuen Long area indicated that the last population-wide flowering took place over 40 years ago. Aerial photographs of Kam Tin, Fanling and Tai Po from the 1960s and 1970s showed no visible signs of flowering on any of the bamboos. Elderly residents in Kam Tin, Yuen Long and Ping Shan (to the west of Yuen Long), however, remembered a mass flowering of these bamboos during the Japanese occupation in the Second World War, suggesting a flowering interval of about 50 years. There was one report of residents gathering the seeds for consumption at this time. Additionally, although the single plant which began flowering in 1995 was reckoned to be "over 100 years old", one elderly resident (65-70 years of age) remembered seeing "balls of flowers" hanging from this plant when he was an adolescent, presumably a reference to the witches broom mentioned earlier. This plant was particularly interesting because its anthers did not dehisce, it was isolated from other plants by between 400 and 1000 metres, and no seed setting has been observed on it thus far. Death of bamboos after flowering is often thought to be related to seed setting, and as this plant was, in effect sterile, it might not have died after its last flowering.

This is the only direct evidence we have of a previous mass flowering of B.flexuosa. If the 50-year cycle postulated is correct, then flowering would have occurred in the mid-1890s 1840s 1790s and 1740s. The original collections of B.flexuosa were made by Peter Osbeck in Guangdong in 1751 (Osbeck 1757; cited in Munro 1868) and were recorded by Munro (1868) as being "6, occasionally 12 feet high","1.5 in" in diameter and with "culmus *suffruticosus,* nanus" (dwarf, partially woody culms). However, But et al. (1985) state that *B.flexuosa* grows to 7-8 m, while McClure (unpublished) records 12 m. One-year-old seedlings in Hong Kong are generally 30-60 cm tall, and so it is quite possible that Osbeck was witnessing a new generation of young seedlings from plants which flowered in the mid-1740s. It is also tempting to speculate on why he was told the intermast period in the plants had not been seen in flower recently.

The only written records of bamboo flowering in Hong Kong are from 1895 (Anonymous), which refer to a mass flowering of *B. tuldoides* the previous year. *B.flexuosa* was much rarer on Hong Kong island and Kowloon than in the N.T. or Lantau (which were then still part of China) (Hance 1872). Given that it was thought to be much smaller than the other sympodial species known from Hong Kong at the time, it is just possible that the flowering of a few *B.flexuosa* may have been overlooked.

Discussion

B..flexuosa and *B. chunii* are bamboos that flower during late winter/early spring, and flowering was probably initiated in December of the previous year. In *B. arundinacea* Retz. from parts of southern India with a pronounced wet and dry climate similar to Hong Kong, flower production is initiated in December, seed drop occurs in waves during February (20%), March (30%) and April (50%), and is rapidly followed by death of the plants (Gadgil and Prasad 1984). Plants of B. blumeana J.A. & J.H. Schultes in the Philippines flowered in 1990 from January to October and then died (Roxas 1985). However, in southern Mexico, *B. paniculata* (Munro) Hackel begins flowering in June (Young 1985), and in China (latitude not given), *B. lapidea, B. rutila* and *B. sinospinosa* reach a peak of flowering in August and September (Anonymous 1974). Seed viability in *B,flexuosa* rapidly falls to just a few percent after one month (personal observation), and spring flowering permits rapid germination and subsequent establishment of seedlings before the onset of the dry season, hence maximizing the chances of seedling survival.

Only one seed drop was observed on *B..flexuosu* and *B. chunii* in Hong Kong. In anemophilous plants, pollination efficiency depends upon the quantity of pollen released per unit time and on the area of receptive stigma available for pollen entrapment (among other factors) (Whitehead 1983). Observations on YLCPRl and HUT1 indicate that the flowering of the first wave of flowers on a branch is highly synchronized, with all florets opening within 4-5 days. During the subsequent flowering, this synchrony is lost and flower production is reduced, especially if the seed production is heavy while the pollen germinability drops rapidly after the first flush of flowers. High incidence of rainfall, common throughout the summer months in Hong Kong, also reduces pollination efficiency (Whitehead 1983).

The 50-year intermast period suggested here is very close to the 45-48 year period for *B. arundinacea* (Gadgil and Prasad 1984) and as we do not know the exact year of flowering during the Second World War, there is likely to be an error margin of about 3-4 years associated with our estimate. Because of this, and because there are no meteorological records from 1940 to 1946, it is not possible to correlate flowering to variations in the weather. However, relative to the weather over the last 50 years in Hong Kong, the years 1990-93 were not particularly unusual. Although we do not know the identities of the thorny bamboos which flowered in southern China during 1994, anecdotal evidence from a couple of villages visited in the Pearl River estuary confirms that these too flowered during the Second World War. Extreme weather conditions, such as frost or drought which might be expected to trigger flowering, might therefore have had prevailed over the whole of southern China. The last drought in Hong Kong was in 1963 with only 963 mm of rain. Photographs from the mid-1960s, however, indicate flowering did not take place at this time. It is therefore unlikely that weather conditions were responsible for the flowering of B. *chunii* and *B.flexuosa* during 1993-95.

Initial pollen viability in *B..flexuosu* (93-99%) is similar to that of Sinarundinaria.fangiana (A. Camus) Keng f. et Wen from western China (Taylor and Qin 1988), and higher than in *Ochlandra* travancorica(Bedd.) Benth. ex Gamble (90%) in India (Venkatesh 1984), *Chusqueu subtessehta* Hitchcock (90%) in Costa Rica (Horn and Clark 1992) and *Schizostachyum dumetorum* (Hance) Munro (70-80%) in Hong Kong (personal observation): It declines more rapidly than in many other grasses (see Chandra and Bhatnagar 1974; Heslop-Harrison 1979; Heslop-Harrison and Heslop-Harrison 1992, for examples). Janzen (1976) postulates that bamboos are obligate outcrossers. However, the potential for outcrossing in anemophilous plants is generally less than in entomophilous plants (Crepet 1983; Regal 1982) and bamboos are among the most specialized of all wind-pollinated plants. In *B.flexuosa,* the rapid loss of pollen viability, our lack of evidence for self-incompatibility and the heavy seed setting on YLCPRl and HUT1 - which were separated by over 1 km and were the only major sources of pollen at the time-combine to suggest that these particular plants were self-pollinated, and that the outcrossing over the whole population during 1994 probably accounted for only a small percentage of seeds. Unlike B. arundinacea in India, B.flexuosa grows in Hong Kong only in small groups of relatively widely spaced plants, and does not presently form large areas of monotypic stands in southern China (although it may have done so in the past). The opportunities for outcrossing with many, closely spaced neighbours as might occur in a monotypic forest and which would be necessary with such a rapid loss of pollen viability, are thus likely to be severely limited in Hong Kong. Selfing would be expected to limit variability in the intermast period of the seedlings, if it had a genetic basis, and contribute to its perpetuation.

Poliinating insects, however, do have the potential to effect cross-pollination in more widely spaced plants. Honeybees (Apis spp.) were seen to help themselves heavily to pollen throughout the day on both plants observed, and were often seen to bite open undehisced anthers to reach the pollen inside. Pollen collected from bee pollen sacs had burst and could not be germinated; but some bees were seen to be covered in pollen, and were occasionally seen to rub against the stigmas of neighbouring florets during the course of their collecting activities. Pollen is released from anthers about 1 cm below the stigma, and bees were never seen rubbing against the stigma of the floret from which they were collecting pollen. Seed eating birds may also effect pollination; Chestnut Buntings *(Embezeria rulik* Pallas), Chestnut Munias *(Lonchura atricephia* L.), Crested Buntings *(Melophus 1athamiJ.E. Grey*), tree sparrows *(Passer montanaL.)* and white-backed Munias *(Lonchura striata* L.) were all seen picking at developing seeds at different times during this study, and occasionally could be seen picking at dangling anthers. Pollination by animals, however, is likely to account only for a tiny percentage.

The seedling stage is the most vulnerable stage in the life of a plant. On 22-24 July and early August 1994, severe floods in the north-western N.T. caused the deaths of many of the seedlings. Much sediment was brought down the Kam Tin river and deposited along its banks and as a result, most seedlings that were growing under the plants died. The dry winter which followed also caused large numbers of seedlings to die. Seedling establishment under plants in *feng shui* woods was very poor, but we do not know whether this was due to low seed setting, with many of the seeds landing on nearby vegetation, or unfavourable conditions for germination and growth under the canopy. The localized opening up of the canopy as a result of flowering allowed vigorous growth of native lpomoea species, which smothered not only the dying bamboos, but the remaining seedlings as well.

The rapid pace of development in the Kam Tin valley and other parts of the N.T. is now the biggest threat to the remaining seedlings. Twenty-one dead plants have already been dug up to make way for development and in most cases, no seedlings remain. Even where they do, various construction activities associated with property development will soon destroy them. On Lantau, almost all of the non-feng shui bamboos grow in and around the village of Tung Chung, close to the new airport, which has been earmarked for massive development for residential purposes in the near future.

The other major influence is the changing attitude towards feng shui bamboos. Whereas once, a flowering bamboo was left to regenerate naturally, many residents now want them removed and dismiss their feng shui role. Some have already been replaced by ornamental shrubs, and there seems to be no plans on the part of village committees or government departments to grow seedlings for replanting at a later date. None of the plants grow within the boundaries of the Country Parks, which are protected areas. The best way to protect B..ftexuosa and B. chunii would be to designate them as protected species, at least for the early years of their establishment.

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Bamboo Resources and in China

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Abstract

This paper reports on the distribution and ecological characteristics of the 37 bamboo genera in China, and the main species used for timber, edible shoot and ornamental purpose.

Bamboo is distributed in 24 provinces, from the Yellow River valley in the warm-temperate zone in the north to Hainan Island in the south, and from Taiwan in the east to southern Tibet in the West. Bamboo resources in China (excluding mixed stands) cover about 4 million ha and account for one-fifth of the world's total. In the last two decades, Chinese taxonomists have conducted extensive research and collection of bamboo resources.

Introduction

China's vast territory includes climatic zones ranging from the frigid and the temperate to the subtropical and the tropical. Also, the country is located in the route of monsoon winds – from Central Asia during winter, and from Southeast Asia during early spring to autumn. These climatic conditions, together with the complex land form with overlapping mountains, crossing rivers and sharp differences in elevation, provide an ideal environment for bamboo.

According to *Flora Republicae Popuhris Sinica Tomus, 19* out of the country's 37 bamboo genera are sympodial, and the remaining 18 are monopodial or amphipodial. Of the 37,18 genera are "new" or newly found. Sympodial bamboos are distributed mostly in the southern and southeastern regions, while monopodial/amphipodial ones are to be generally found in the area between the Yellow River valley and Nanling Mountain, with the most centralized distribution being in the Yangzhi River valley. Table 1 lists the bamboo resources and stand areas in the main distribution areas.

Table 1: The bamboo resources and stand areas in the main distribution areas in China

Province	Genera	Species	Total area ('000 ha)
Fujian	16	110	617.0
Jiangxi	20	100	597.0
Hunan	20	60-100	562.2
Zhejiang	19	130	487.0
Guangdong	24	150	352.3
Yunnan	26	220	331.0
Sichuan	15	94	340.0
Guangxi	19	96	213.3
Taiwan	18	70	184.5
Guizhou	20	80	60.9
Anhui	9	40	65.3
Hainan	8	25	55.0
Hubei	7	30	73.3
Gangsu	7	16	60.8
Jiangsu	10	56	40.0
Henan	6	24	33.4
Shanxi	8	26	31.4
TOTAL			4 104.4

The main bamboo genera in China's high mountain areas include *Fargesia, Yushania, Thamnocalamus* and *Bashania,* with more than 130 species mostly distributed in the western and south-western regions to the south of Qinling Mountain - including Sichuan, western Guizhou and northern Yunnan – over an area of 1 million ha (including mixed stands). These bamboo stands are mostly wild, and are used mainly as food for the giant panda and as raw material for the pulp industry. In recent times, the stand area has decreased because of large-scale flowering and subsequent death of clumps.

Bambusa, Dendrocalamopsis and *Dendrocalamus* are the most widely distributed and main clumping bamboo genera in southern China, including Taiwan, southern Fujian, Guangdong, Hainan, Guangxi and southern Yunnan. The species in these three genera are more than 100, with over 60 species of *Bambusa* distributed mostly in Guangdong and Guangxi, and *Dendrocalamus* mostly in Yunnan. They grow in the plains, river banks, homesteads, valleys and hilly areas, covering over 700 000 ha. The main species in these genera have wide-ranging uses, high economic value and good viability for plantations. For example, *B. textilis* plantation areas in Guangning County of Guangdong exceed 30 000 ha, concentrated along the Shuijiang River bank over a long distance to form what is known as the 'Shuijiang Bamboo Corridor'.

Neosinocalamus is another important bamboo genus in the south-western areas (mainly in Sichuan and nearby regions), with its soft culm suitable for weaving and pulp making. *Gigantochloa,* with its 8-10 species yielding superior quality shoot and timber, is distributed in the monsoonal regions in the middle and lower hills, valleys and tableland of Yunnan's tropical areas. Since most *Gigantochloa* species in China are distributed in the wild, their utility is restricted.

Phyllostachys is perhaps the most abundant and important genus in China, and is widely spread in almost all bamboo distribution areas. The genus consists of 48 species, among which *P. heterocycla* var. *pubescens* is the main one, which cover 2.8 million ha, almost two-thirds of the total bamboo stand area in the country. Its annual timber yield is above 10 million tonnes, and it is used in building, weaving, plywood making and paper making. Its shoots, harvested at the rate of 0.7-0.8 million tonnes per year, are highly valued for their quality. *P.praecox,* the species which yields the best quality shoots, is distributed in Jiangsu and Zhejiang Provinces, with a plantation area of 13 000 ha. Its management is perhaps the most intensive among the different bamboo species, and its high-yielding stands can produce 30 tonnes of shoots per hectare, generating an income of about US$38 000 - 50 000 per hectare. *P. glauca, P. bambusoides, P. heteroclada, P. nidularia* and *P. nigra* var. *henonis* are also cultivated. P. *glauca* in Luoyang (Henan), *P. bambusoides* var. lacrimedeaein Boai (Henan), and *P. heteroclada* in Yiyang (Hunan) and Shucheng (Anhui) are some notable examples.

Brachystachyum is a genus particular to eastern China, with only one species. It is distributed, often wild, in Jiangsu, Zhejiang, Anhui and Jiangxi

Provinces, and grows in wooded areas or mixed with brushwood, as understorey in lower hills. Since its culms are short, it is mostly used for fence, whisk handle and frame for climbing plants such as melon. Recent land developments in lower hilly areas have contributed to the decrease of this genus.

Qiongzhuca is a well-known genus in China, and is distributed mainly in Jinshajiang River valley of Sichuan, Yunnan and Guizhou. Its type species *Q. tumidinoda* is a species much valued for its delicious shoots, which are used as fresh food or dried for export. Its peculiar culm knot makes it useful in handicrafts and landscaping. Natural stands of this species can be found in Luibo, Xuyong and Mabian Counties of Sichuan Province, growing within broadleaf stands or forming single stands in middle hilly areas at an elevation of 1500 to 2 200 metres above sea level. Melocanna and *Thyrsostachys* are cultivated extensively on small-scale to the south of the southern subtropical regions. They have not been reported in natural distribution.

Among China's medium and small bamboos, *Pleioblastus* and *Indocalamus* are two genera distributed most widely all over southern China, south of the Huanghe River. The former often grows in lower hilly areas, while the latter is found in wooded areas, valleys and banks of streams at elevations less than 1 000 m. Most *Indocalamus* species have big, broad leaves, which are used as padding for bamboo hats and to wrap the Chinese food *zongi,* while its culms find use as pen stands. Table 2 gives a listing of the genera, distribution pattern and uses.

Table 2: Distribution and uses of some bamboo genera in China

Genus	No.	Distribution	Niche	Main uses
Acidosasa	*8*	Fujian, Jiangxi, Zhejiang, Hunan	Low hills, valleys lowlands	Shoot, total culm
Ampelocalamus	*2*	Guizhou, Hainan	Hills, alt. 500 m	Weaving, ornamental
Bambusa	*63*	Guangdong, Hainan, Guangxi, Jiangxi, Fujian, Yunnan, Taiwan, Hunan	Lowlands, mountains, riversides, homestead	building,.strip, shoot, pulp
Bashania	*4*	Shanxi, Gnngsu, Sichuan, Hubei	Hills, alt 1 000-3 000 m	Pen stand, frame

Genus	No.	Distribution	Niche	Main uses
Bracbystacbyum	*1*	Jiangsu, Anhui, Zhejiang, Jiangxi	Wild in low hills, lowlands	Whiskpole, frame
Cephalostachyum	*4*	Yunnan	Broadleaf woods alt. 1 200-2 000 m	timber, shoot, weaving
Chimonobambusa	*10-20*	Sichuan, Guizhou, Guangxi, Yunnan	Damp ditches, alt. 700-2 000 m	Shoot+, ornamental
Chimonocalamus	*9*	Southern Yunnan, South-East Tibet	Hills, alt. 1,100-2 000 m mixed evergreen	Shoot, building
Dendrocalamopsis	*9*	Guangdong, Taiwan, Guangxi, Hainan, Hunan, Fujiang	Valleys, hill foots, riversides, roadsides	shoot*, frame, tool, pulp
Dendrocalamus	*30*	Yunnan, Guangdong, Guangxi, Hainan, Taiwan, Guizhou, Fujian	Lower hill, valley, mixed with broadleaf alt. <1 000 m	building+, strip+, shoot+*
Drepanostachyum	*6*	Guizhou, Sichuan, Yunnan, Taiwan	Steep hills aft. <1 000 m limestone hill	Weaving, pulp
Fargesia	*74-77*	Sichuan, Yunnan, Tibet, Gangsu	Understorey alt. 1300-3 000 m	Food for giant panda, weaving, Pulp
Ferrocalamus	*1*	Yunnan	Valleys, hill ridges, alt. 1 000 m	Arrow, needle, leaf thatch
Gelidocalamus	*9*	Guangxi, Guizhou, Jiangxi, Hunan	Hills, alt. 300-1 200 m	Fence, frame
Gigantochioa	*8-10*	Yunnan, Guangdong, Taiwan	Lower hills, valleys, tablelands, tropical monsoon woods, mixed deciduous forests, alt. 500-1,000 m	Furniture, farm tool, weaving, fresh/dry shoot
Indocalamus	*21*	South of Yangzhi River	Valleys, hills, understorey, alt. 100 m	Pen stand, leaf for hat and padding.

Genus	No.	Distribution	Niche	Main uses
Indosasa	13	Guangxi, Yunnan, Hunan, Guangdong, Guizhou	Low hills, lowlands, alt. <1000 m	Building, shoot, ornamental
Melocalamus	5	Yunnan, Tibet	Riversides, valleys, hills in evergreen forests	strip, weaving, shoot, edible fruit
Melocanna	1	Guangdong, Taiwan, Hong Kong, Guangxi		Pulp ma king, edible fruit
Metasasa	2	Guangdong	Hilly areas	
Monocladus	4	Hainan, Guangdong, Guangxi	Limestone and granite hills, understorey	pulp, tool, leaf fodder
Neomicracalamus	2	Tibet, Yunnan	Deciduous, evergreen forests, riversides	pulp, shoot, string
Neosinocalamus	1	Sichuan, Guangxi, Hunan, Guizhou, Hubei, Yunnan, Shanxi, Gangsu	Hills, lowlands alt. 300-1 000 m	building, weaving, pulp
Oligostachyum	.3	Fujian, Jiangxi, Zhejiang, Hainan, Guangdong, Guangxi	Low hills, valleys, lowlands	Timber, strip, shoot*
Phyllostachys	48	Provinces south of Qinling Mountain and Huihe River	Hills, lowlands, valleys, plains, homesteads	Building, strip, weaving furniture
Pleioblastus	21	South of Yangzhi River	Low hills, valleys, lowland	Fence, frame
Pseudosasa	18	Guangdong, Fujian, Hunan, Zhejiang, Henan	Low hills, low lands, humid valleys	Fishing rod, skiing pole, furniture
Pseudostadyum		Yunnan, Guangdong, Guangxi, Tibet	Valleys with good soil, alt. 1000-4 000 m	fish screen, strip
Qingzhuea	8	Sichuan, Guizhou, Yunnan, Hubei	Deciduous, evergreen alt. 1 500-2 600 m	Handicrafts+, shoot+

Genus	No.	Distribution	Niche	Main uses
Sasa	12	Jiangsu, Zhejiang, Hubei, Guangxi, Guangdong, Anhui	Hilly areas, humid river-side, alt. 1 000-2 000m	Greening, ornamental
Schizostachyum	9	Guangdong, Guangxi, Jiangxi, Yunnan,Taiwan, Hunan, Hainan,	Low foothills, valleys, muggy groves alt. <1 000 m	Pulp making, weaving, instruments, shoot
Semiarundinaria	1	Jiangsu, Zhejiang		
Sbibatea	7	Jiangsu, Zhejiang, Fujian, Jiangxi, Anhui, Taiwan	Understorey in hills, valleys, mixed with shrubs	Hedge, ornamental
Sinobambusa	13	Guangdong, Fujian, Guangxi, Jiangxi, Guizhou, Sichuan, Yunnan, Jiangsu	Low hills, lowlands	Timber, strip
Thamnocalamus	1	Southern Tibet	Alt. 2 000-2 500 m	
Thyrsostacbys	2	Yunnan, Guangdong, Taiwan, Fujian	Cultivated in homesteads	timber, frame, ornament, tool
Yushania	55	Sichuan, Yunnan, Tibet, Taiwan, Guangxi, Guizhou	Understorey alt. 1000-3 000 m	Fence, tool, weaving, shoot*

Note: * = some species; + = only superior species

Use of Bamboo Resources

The main use of bamboo is as timber for house building, furniture, farm implements and other articles. Bamboo shoot is considered a health food. In recent years, the use of bamboo culm as the raw material for the manufacture of pulp and plywood has rapidly increased. Bamboo's role in stabilizing river and water reservoir embankments, and in protecting water sources, has also been widely recognized. Many species of bamboo are beautiful in appearance, and this has come to be appreciated by gardeners, interior designers and landscape artists who use it to beautify the environment. In spite of such developments, only 30% of China's 37 genera and only 10-15% of its 500-odd species have been developed and put to use, leading to the dwindling of the neglected ones.

Bamboo timber

The most important use of bamboo is as timber. In China, there are over 120 species used mainly for its timber. About three-fifths of these are sympodial, and the remaining monopodial or amphipodial. Based on specific use, bamboo timber may be classified as strip timber, culm timber and pulp timber.

Strip timber

This type of bamboo timber is pliable, yet tough with clear layer division on stripping to facilitate its use in weaving and in handicrafts. Among monopodial/amphipodial bamboos, the main genus used for preparing strips (slivers) is Phyllostachys. Although many species of *Phyllostachys* could be used for the purpose, the better ones include *P. heterocycla* var. pubescens, *P.* feteroclada,*P. glauca, P. augusta, P. nigra* var. *benonis, P. bambusoides, P. meyeri, P. bessetii, P. mannii* and *P. parvifolia.* Other bamboos used for making slivers are *Indosasa spongiosa, Sinobambusa seminudu* and *S. striata.*

Among sympodial bamboos, there are several genera that yield excellent slivers: *Cepbalostacbyum, Schizostachyum, Bambusa, Neosinocalamus,* Dendrocalamus and *Meloculumus.* The better species for strip-making are S.fungbomii, *S. pseudolima, S. Chinese, B. textilis, B. pallida, B. chungii, B. distegia, B. intermedeu, B. surreta, B. lenta, M. elevatissimus* and *N. affinis.*

Culm timber

The bamboo species used for culm timber have straight culms, with thick and tough culm wall, characteristics that would suit their use in making building materials, trellis (frame), furniture, farm implements and other items. Besides *P. heterocycla* var. *pubescens,* monopodial/amphipodial species suitable for culm timber include *P. bambusoides, P. sulphyrea cv. viridis, P. iridescens, P. nigra, P. incarnata, P. viridi-glaucescens, P. nuda, Acidosasa edulis, A. gigantea, Oligostachyum sulcatum, Indosasa crassiflora, Pseudosasa amabilis,* etc. *Pseudosasa amabilis,* which is being exported for the past 200 years, occupies the prime place among China's bamboo culm export. With a straight culm, flat nodes and tough culm walls, it is exceptionally suitable for making fishing rods and ski poles.

Most species of the sympodial type, including such genera as *Bambusa, Dendrocalamus, Dendrocalamopsis, Thyrsostachys, Chimonocalamus* and

Gigantochloa, could be used for culm timber. Superior among them are: *Bambusa blumeana, B. lapidea, B. sinospinosa, B. rigida, B. tulda, B. prominens, B. pervariabilis, Dendrocalamus bambusoides, D. barbatus, D. giganteus, D. membranaceus, D. strictus, Thyrsostachys siamensis, Cbimonocalamus delicatus, C. longiusulus,* etc. Of these, *B. blumeana, B. lapidea, C. delicatus,* C. *longiusulus,* etc., are ideal for building construction because of their high durability, good resistance to pests, and pliable and tough culms.

Pulp timber

Bamboo has a cellulosic content of 40-60%, average fibre length of over 2 mm, fibre thickness of 0.01 mm, and a fibre length-thickness ratio of 150-200. These properties make it an ideal raw material for medium and high-quality paper making. Many bamboo species can be used for pulp, but the best ones are *Dendrocalamus minor, D. strictrrs, D. latiflorus, Bambusa textilis, B. lapidea, B. tulda, B. pervariabilis, Neosinocalamus affinis, Schizostachyum pseudolima, S.* bananese, *S. .fungbormii, Phyllostacbys augusta, P. heteroclada, P. beterocycla* var. *pubescens, P. glauca, Chimonobambusa utilis,* etc.

Bamboo shoot

Bamboo shoot is now widely recognized as a health food. It can be eaten both fresh and dried, canned or as other forms of convenient food. China has over 100 species which produce edible shoots.

Among monopodial/amphipodial type, shoots of *Phyllostachys, Cbimonobambusa, Qingzbuea, Acidosasa* and *Oligostachyum* are known for their edible qualities. Delicious shoots are produced by *P. heterocycla* var. *pubescens, P. dulcis, P. iridescens, P.prominen.s, P. vivax, P. n igella, P.praecox, P. glabrata, P..fimbriliguIa, P. propinqua, P. nuda, P. elegans, P.flexuosa, P. parviflora, Q. tumidinoda, C. quaduagularis, C. neopulpurea* and *C. utilis,*

Among sympodial bamboos, shoots of most species of *Dendrocalamopsis, Cbimonocalamus* and *Dendrocalamus* are edible, though some need proper treatment before eating. The species well known for their delectable shoots include *Dendrocalamus asper, D. brandisii, D. bamiltonii, D. latiflorus, D. farinosus, Dendrocalamopsis beecheyana, D. oldhamii, D. edulis, D. stenoaurita, D. variostriata, Chimonocalamus delicatus, C. dumosus, C. longiligulatus, C. makuanensis, Bambusa gibboides, Gigantocbloa levis, G. albociliata* and *G. ligulata.*

Bamboo species for ornamental purpose

For greening and beautifying the environment, bamboo is a low-cost yet effective material. From *Dendrocalamus giganteus* standing 20-30 III high to *Shibatea chinensis* which is just 0.2-0.3 m high, there are several bamboo species that could be used for the purpose. While it is the colouration or morphology of the culm that makes some species attractive, it is the foliage that makes others appealing. *Sasa.fortunei, S. auricoma, S. pygmaea, S. argenteastriatus, Pleioblastus gramineus, Bambusa multiplex cv. fernLeaf, Indocalamus latifolius, I. herkiostii,* etc. are utilized for their leaves.

Bamboo species with colour stripes or spots, square culm, nodes or internodes of peculiar shape, etc. are also chosen for ornamental use. Among these, the more famous include *Bambrrsa vulgaris cv. wamin, B. vulgaris cv. vittata, B. ventricosa, B. tuldoides cv. swollen internode, B. multiplex, Qingzhea tumidinoda, Ph yllostach ys heteroc ycla, P. heterocycla cv. tao kiang, P. aurea, P. vivax flaureaocaulis, P. aureosulcata, f. spectabili.s, P. nigra, Phambusoides f. lacrimadeae, P. glauca cv. yuozhu, Dendrocalamus latiflorus, Chimonobambusa szechluanensis var. flexuosa. C. quadrangularis, Indosasa shibataedes, Neosinocalamus affinis cv. flavidorivens, Gigantochloa pseudoarundinacea* and *G. ligulata.*

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Diversity and Distribution of New World Bamboos, with Special Emphasis on the Bambuseae[1]

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Abstract

The bamboo species composition of the New World has been virtually unknown until very recently, even though the number of bamboo species in America nearly surpasses the number in Asia. It is estimated that there are 46 genera and approximately 515 species of bamboo, both woody and herbaceous, extending from the United States to Chile and occurring in humid or dry sea-level forest to high Andean paramos. Nearly 96% of the genera are endemic to the New World; only two genera - Arundinaria (woody) and Streptogyna (herbaceous) have a bihemispheric distribution pattern. The world's greatest centre of bamboo diversity is located in the Atlantic coastal rain forest of Brazil, with five endemic genera and approximately 27 endemic species. The genus *Chusquea* has the widest latitudinal range of any bamboo genus. The genus *Guadua* dominates enormous areas up to 122 000 km^2 in the south-west Brazilian Amazon and neighbouring Peru, and it is the most economically important bamboo in the New World. This paper discusses the diversity of the New World American genera and illustrates their distribution.

The biological diversity of the New World bamboos needs further study in order to effectively approach bio-geographic, phylogenetic and taxonomic questions. Much more has to be done to answer important questions on ecology, natural history and population structure of the New World bamboos. In the whole spectrum of research and practical applications, bamboo remains an ideal study case for establishing a solid linkage between economic development and environmental conservation strategies. It is suggested that some social problems in the tropics can partially be solved by making bamboo a source of economic growth, with strong emphasis on the sustainable management of this important plant.

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Bamboo Strategies for Improvement

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Abstract

Bamboo is one of the most useful multi-purpose plant resource in forests and villages. In most bamboo-growing countries, it is in short supply. In the future, the gap between supply and demand is likely to widen further and huge shortfalls likely to occur. Production of bamboos should hence be increased, and to meet the demand for planting stock, large-scale production of propagules of high-yielding species are needed. For this purpose, some of the most useful species relevant to the developing countries are identified have been prioritized.

Both short-term and long-term strategies for the improvement and breeding of bamboos have been proposed. The short-term strategy emphasizes immediate enhancement of productivity of bamboos in Asia through exploration, identification and selection of useful species/provenances/clones, their mass multiplication, and establishment of clone banks and pilot plantations. Conservation of bamboo germplasm and diversity, both at national and regional levels, are also considered as simultaneous activities under the short-term strategy.

Under the long-term strategy, more research is proposed on genetic analysis of useful species for the selection of superior varieties, and their conservation and propagation. The establishment of seed stands in the region consisting of flowering genotype of the same species collected from different countries and localities is recommended to facilitate the production and regular supply of seeds. In this regard, international cooperation, especially in germplasm exchange, should be encouraged and improved.

Introduction

There are more than 10 million ha of bamboo stands, both natural and cultivated, with some 1225 species distributed throughout the subtropical and south temperate zones of the world. About 80% of these are in India and the Asia-Pacific region, including Japan. In the South and Southeast Asia, around 85% of the bamboos are sympodial type and the rest monopodial. Among them, more than 150 species are tall and large, having high economic value. In Australia and the Pacific islands, there are fewer bamboo species with more scattered distribution. A good inventory for some of these regions is long overdue (Williams and Rao 1994).

In the Americas, bamboo grow in tropical and subtropical zones. In Latin American countries, *Guadua angustifolia* is widely used for construction purposes. At higher altitudes and in temperate climate, Chusquea *scandens* is used for construction, fodder and fencing, as well as for making baskets, tools and other useful objects in daily life. Amazonian Indians in Venezuela make blowpipes from *Arthrostylidium scbomburgkii* for hunting with poisoned arrows. *Arundinaria gigantea* and *A. tecta* are the only native bamboos in the USA (McClure 1966).

The African bamboo region has only three genera – *Oreobambos, Oxytenanthera* and *Arundinaria. A. alpina* forest, located in Kenyan mountainous area, is spread over 130 000 ha, while *0. ahyssinica* in Ethiopia covers 100 000 ha. In the island of Madagascar, there are 11 genera with about 40 species (Fu Maoyi and Xiao Jianghua 1994; Tewari 1992). Many of these are endemic.

Only two genera, *Bambusa* and *Arundinaria,* have world-wide distribution: the former in the tropical zone and the latter in the subtropical and warm temperate zones. *Bambusa vulgarisis* the only species which is pantropical.

Priority species

Nineteen bamboo species of considerable economic importance in many countries were given first priority for greater promotion. They include *six* species of *Bambusa,* four species of *Dendrocalamus,* three species of *Gigantochloa,* and one species each of *Cephalostachyum, Guadua, Ochlandra,* Melocanna, *Phyllostachys* and *Thyrsostachys.* Another 18 species were listed as second priority. The criteria followed were the high value of these species for utilization and environmental rehabilitation, degree of domestication, climatic ranges, need for genetic conservation and easy availability. The status of genetic resources for each species have also been evaluated (Williams and Rao 1994).

The present bamboo consumption and resource status

In Asia, Africa and South America, bamboos are crucial for housing, agricultural implements, handicrafts and paper industries. It has been estimated that 2.5 billion people depend on or use bamboo materials with a value of US$7 billion per annum (Liese 1992). In addition, bamboo is extensively used for making pulp, paper and domestic commodities, and in cottage industries. Bamboo shoots are used as vegetables throughout the world, especially in South and Southeast Asia. The sprouts are nutritious, tasty and cheap. Dendrocalamus asper, D. brandisii and D. merrillianus are cultivated commercially in Thailand and the Philippines for shoot production. Bamboo consumption by end-users in different countries of the Asia-Pacific region has been estimated. It is noted that in these countries bamboos are used mainly in construction work (Table 1).

Table 1: Estimated consumption of bamboos for various uses in different countries of the Asia-Pacific region (indicated as percentages of the total)

Country	Construction		Rural use	Pack-aging	Pulp	Other uses
	Housing	Others				
Bangladesh	50	10	20	5	10	5
India	6	6	14	2		6
Indonesia	16	14	8	6	6612	44
Japan	24	7	18	7	4	40
Malaysia					17	76
Myanmar	30	32	32	5	-	1
Nepal	50	20	10	10		10
The Philippines	80		15	2	-	3
Thailand	33	20	6		8	33

(Sources: Ahmed and Haron 1994; Poudyal 1991; Sharma 1980; Yudodibroto 1987)

The world's annual production of bamboo has been estimated to be more than 20 million tonnes (Sharma 1980), with wide annual fluctuation because of large-scale periodic death of bamboo clumps from gregarious flowering. The annual yield of bamboos varies between 0.2 to 4.0 tonnes per hectare, depending on the species and areas of cultivation

In Bangladesh, the village sources annually supply about 528 million bamboo culms (80%) and forests supply 128 million (20%). The current estimated demand is 706 million culms, which will increase to about 900 million culms by the year 2013 (Banik 1992). An acute shortfall in supply is expected by the year 2000 because of the large-scale death of muli bamboo (Melocanna *buccifera),* a major forest bamboo species, as a result of gregarious flowering. Forest area under bamboo is also decreasing at the rate of about 2% because of overexploitation, poor maintenance and low yield.

China has a total area of 3.5 million ha of bamboo stands, making up nearly 3% of China's total forest area and one-quarter of the world's total bamboo forest area. In China, bamboo is mainly distributed along the Changjiang (Yangtze) River basin, and in the hilly areas and plains of tropical and subtropical zones, 3 000 m above sea level south of the Changjiang River. The annual bamboo output is about 6-7 million tonnes (Wu Bo and Ma Naixun 1987). The primary species is *Phyllostachys heterocycla* var. *pubescens,* which makes up about 65% of China's total bamboo forest area. Other major species are *Bambusa textilis* and *B. pervariabilis,* and *Dendrocalamus* latiflorus(for shoots). It is estimated that some 600 000 tonnes of pulp, 650 million farm tools, 80 million handicraft items and 200 million pieces of furniture are produced annually (Zhu and Zhang 1992). Annual exports amount to US$50 million. The area under intensive management does not exceed 10% of the total bamboo area, while the less superior bamboo groves which are cut but not cultivated add up to more than 60% of the total.

The total annual production of bamboo in India has been estimated to be around 5 million tonnes of which about 3.5 million tonnes are required by the pulp and paper industry (Sharma 1980). Future projections show a shortfall of 4.32 million tonnes of raw material in this industry by the turn of the 21st Century (Adkoli 1990).

Bamboo is used in Nepal in 180 different ways, the most visible ones being housing, scaffolding and basketry (Poudyal 1991).

It is estimated that about 3.3 million tonnes of bamboos are available from the forests of Peninsular Malaysia (Abd. Latif and Abd. Razak 1992). At present, there is a wide demand-supply gap (Ahmed and Haron 1994).

The annual production of bamboos in Thailand has been estimated to be about 600 million culms (Boonchoob 1988).

According to a report made by the Bureau of Forest Department in 1979, only about 17 million culms or roughly 80 000 clumps were present in Philippines. Obviously, there is a need to improve the productivity of bamboo to meet local as well as foreign demands.

In Indonesia, a very rough estimate puts the total bamboo production from Java, Bali, Sumatra'and South Sulawesi at 29 to 146 million culms (Yudodibroto 1987).

Supply-demand details for other countries can be obtained from reports presented in the past bamboos conferences.

It is obvious that in the near future, the demand for bamboos in most countries will increase more than the supply if bamboo forests are not scientifically maintained and the cultivation of bamboo is not promoted. This will accelerate the depletion of natural stock and erode the genetic material (Rao 1992) It was estimated that during 1981-90 about 15.4 million ha were deforested annually in the tropical zone of the world (Anonymous 1993). How much of this applies to bamboo forest is hard to estimate. Conservation and maintenance of bamboo genetic resources, simultaneous improvement of productivity, and sustainable use are the main actions to be taken immediately to reduce the deficits.

Planting Materials

Because of the scarcity of bamboo resources, many countries have begun emphasizing the need to raise bamboo plantations for increasing production, which will also assist to conserve naturally occurring bamboos and reduce the problem of over-harvesting to some extent.

Following are the major impediments in raising large-scale plantations (Banik 1992; Anonymous 1994b):

- Unavailability of bamboo seedlings every year because of the long flowering interval of many species;
- Some of the species rarely or do not at all flower (Table 2);
- Little is known about bamboo seeds, their structure, sterility, germination, storage and seedling behaviour;
- Easy and mass macropropagation techniques (both *in* vivoand *in vitro)* are yet to be perfected; and
- Value of bamboo cultivation is rarely appreciated, More efforts need

to be made to raise plantations on degraded lands, logged-over forests and semi-arid lands with marginal soils, which will help improve the environment and increase biomass.

Table 2: Seed characters of some bamboo species in the Asia-Pacific region

Name of the species	Seed size and weight
Bambusa balcooa	Do not produce seed.
B. bambos	Small like paddy grain, 1 000 seeds per 10 g.
B. bambos var. *spinosa*	Small like wheat grain, average 1 325 seeds per 10 g.
B. glaucesceus	Small like wheat grain, average 151 seeds per 10 g.
B. longispiculata	Small like wheat grain, average 145 seeds per 10 g.
B. polymorpha	Small like wheat grain, average 1 250 seeds per 10 g.
B. tulda	Small like wheat grain, average 150 seeds per 10 g.
B. vulgar-is	Do not produce seed.
Dendroca1amu.s brandisii	Small like coriander seeds, 615 seeds per 10 g
D. longispathus	Small like coriander seeds, .l 350 seeds per 10 g.
D. strictus	Small like wheat grain, average 515 seeds per 10 g.
Melocalamus compactiflorus	Like chest nut or betel nut. Seed weight varies from 20 to 200 per 10 g.
Melocanna baccifera	Large and obliquely ovoid, thick and fleshy, green and smooth surface. The apex terminates in a curved beak. Seed size ranges from 35 to i 10 mm in length and 22 to 60 mm in diameter. Seed weight varies from 45 to 70 per kg.
Oxytenanthera nigrociliata	Small like wheat grain, average 265 seeds per 10 g
Thyrsostachys siamensis	Small like paddy grain, average 490 seeds per 10 g

Seed and seedling propagules

As bamboos produce seeds after long intervals, information on different aspects of seed production and propagation is limited.

Bamboo produces single-seeded fruits, with a thin pericarp covering the seed (Caryopsis). In general, bamboo seeds are very different both in size and weight depending on the species (Table 2). Seeds are generally small, grain-like and wheat coloured; but those of M. baccifera are big, fleshy, onion-like, greenish and may be termed as “bacciform” (Banik 1994a). Whether they are true caryopsis is yet to be determined. In general, the number of seeds of different species per kilogram varies from 13 000 to 15 000 (Banik 1987; Liese 1985).

Seed production per clump varies from 30-80 g in B. bambos, 15-17 g in B. glaucescens and 40-90 g in D. longispathus. One full-grown clump of *Melocanna baccifera* produces 5-7 kg seeds during flowering time and 25-40 kg before dying.

Fresh seeds germinate better than stored ones. Germination percentage is higher under shade than in direct sunlight (Table 3). In other words, bamboos prefer shade (Banik 1993). The germination medium (soil, and cow dung or other organic medium in 3:l ratio) should be wet, but not waterlogged. Seeds start germinating within 3-7 days of sowing and continue the process up to 15-25 days (Banik 1987).

Table 3: Seed germination under different light/shade conditions and seed longevity period

Name of the species	Germination percentage		Longevity **(days)**
	In sunlight	Under shade	
Bambusa bambos	*23.6*	*49.5*	*40*
B. glaucescens	*26*	*40.2*	*35*
B. tulda	*30.7*	*58.2*	*35*
Dendrocalamus longispathus	*33.4*	*61.2*	*55*
Melocama baccifera	33	*79.8*	*35*
Oxytenantbera nigrociliata	39		50

Seed viability lasts only for one to two months. It was possible to extend seed viability of *B. tulda,* D. strictus and *Phyhtachys* spp. for a few weeks by storing the seeds over calcium chloride or silica gel either at room temperature or inside a desiccator (Banik 1987; Vermah and Bahadur 1980). Sur et al. (1988) observed that soaking-drying treatment with a low concentration of disodium hydrogen phosphate (10^{-4}M) was better than water for maintaining the vigour and viability of seeds of D. strictus. The fleshy seeds of M. baccifera retained viability up to 45 days when stored in air-conditioned room, compared with 35 days at normal room temperature, and up to ***50*** days when stored with dry sand in jute bags (Banik 1994a).

Initially, seedlings do best in partial shade; hence, both direct sunlight and complete shading over the seedling are be avoided. Polythene bags, in which the seedlings are raised, are to be shifted from one bed to another at three months interval. This helps in minimizing the rhizome anchorage, and transportation becomes easy with less or no damage to the root and rhizome system (Banik 1994a).

Wild seedlings are another source of planting material. They are often seen as a thick mat on the ground just below the flowering mother clumps. These seedlings compete strongly for survival. Hence, they should be thinned out to minimize the competition (Banik 1988). The seedlings collected should be transplanted to polythene bags containing soil mixed with cow dung or other organic matter (3:l). Initially, the seedlings have to be kept under shade for three to five days for hardening. For better survival (about SO-90%) in the field, less than one-year-old seedlings should not be transplanted. Rainy season is the best time for planting of seedlings in the field in subtropical conditions-

Macro and micro-propagules

A bamboo must develop all the component parts – the leafy axis, rhizome and root. Failure in development of any of these parts will lead to complete failure of a propagule (Banik 1980).

The following vegetative propagation methods have been studied in different countries of the region (Banik 1995).

Off set and rhizome

These are the traditional, and perhaps the most commonly used propagules. Generally, one or two-year-old offsets give best results, while older propagules (three years or more) give progressively poorer results. In Bangladesh, offset's survival is found to be higher when collected and planted in April (44-76%) than in June (3-38%). However, thin-walled species show less success in offset planting. The use of rhizome for propagating bamboo has been limited mostly to non-clump forming species.

Culm or stem-cutting

Culm or stem segments are also used for propagating bamboos. The success and survival are higher (40-80%) than offset method. These may be further enhanced by applying growth regulators, as well as by using cuttings with a higher endogenous level of carbohydrate (Surendran and Seethalakshmi 1985). Split-culm cuttings reduce the weight of the planting stock in comparison with whole culm cuttings (Vivekanandan 1987).

Branch cutting

In certain thick-walled bamboos, one may occasionally find the presence of aerial roots, and sometimes aerial rhizomes, at the base of culm branches. These branches can be used as planting materials and are termed as "pre-rooted and pre-rhizomed cuttings" (Banik 1980). Such aerial roots and rhizomes can also be induced at the branch bases of some bamboo species by chopping the culm tops and removing the newly emerging culms from the clumps (Banik 1984). Such cuttings perform better as a planting material than normal branch cuttings. The ability of these cuttings for rooting and rhizome formation vary from 70-95% (Banik 1984). Survival rate is also high at 85-97% in the field.

Layering

The layered stem, when rooted, is detached to become a new plant growing with its own roots. Three types of layering procedures for bamboo have been described by McClure (1966). There are different types of layering: ground or simple layering, air-layering or marcotting and stump layering.

Macroproliferation of bamboo seedlings

The multiplication of a bamboo seedling through rhizome separation is known as macroproliferation technique (Banik 1987). Five to nine-months-old seedlings of *B. tulda* can be multiplied two to five times in number through this technique. Every year, the seedling can be multiplied at the same rate and a large portion of them may be planted while keeping enough stock for future macroproliferation. The survival rate of these multiplied seedlings is high (almost 100%).

Success in micropropagation of bamboos

The application of the methods of micropropagation is, still limited since there has been only partial success could be achieved using nodes or other materials from mature, adult bamboo plants for cloning selected individuals (making multiple, identical copies of the parent plant) (Ramanuja Rae and Usha Rao 1990). So far, only about 4-10% of the shoots obtained from mature nodes (depending on the species) in culture could be induced to root. Better success has been obtained only with the explants from seedling. However, seeds and seedlings are not always available, and this does not satisfy the objective of cloning mature and selected elite bamboos. At present, somatic embryogenesis is possible only from juvenile tissue, either from seed or seedling (Ramanuja Rao et al. 1990). The status of micropropagation of bamboos under *in vitro* condition has been recently reviewed, and so far plant materials of 20 genera and 73 species have been studied and their tissue culture requirements determined (Zamora 1994). Fourteen out of the 19 priority species have been studied, and it has been established that plantlets of these can be produced in large numbers. Nodal and shoot explants, plantlets regenerated from callus tissues which developed from embryos or seedlings, serve as base materials for propagation. With further improvements many of these methods can be conveniently used to obtain and supply vast number of planting materials for large-scale plantations (Ramanuja Rao 1994).

Methods have also been well established for mass multiplication of bamboos using static liquid cultures. From a single axillary bud, up to 300 shoots can be produced in one month. Root induction takes two more weeks, and after four months they can be transferred to the field. Successful and easy to follow protocols have been developed for *Bambusa bumbos, B. polymorpha, Dendrocalumus asper, D. giganteus, D. strictus* and *Phyllostachys edulis* (Anonymous 1994a).

Research for Genetic improvement

In Southeast Asia, bamboos grow not only in natural forests, but also in village groves cultivated to meet the people's needs. This provides a great opportunity for identifying and selecting bamboo species on the basis of need and desired economic characters. The important point to remember is that bamboos are mostly wild populations which are not yet greatly changed by cultivation methods practised. This gives the bamboo breeder an excellent opportunity for improvements. However, bamboos usually do not seed annually and hence, conventional progeny testing is not possible. Therefore, it is not always possible to test and measure heritability of desired characters in the progenies of selected individual clumps of bamboo species (Banik 1993). Owing to the same reason, any planned hybridization program aimed at combining different desired characters in a hybrid and generating variability in the offspring are also very diflicult (Williams et al. 1995). Tissue culture and other biotechnological methods may yield valuable results.

Short-term strategy and improvement programs

To meet the ever-increasing demand for bamboo, large-scale plantations with high-yielding species and genotypes should be raised. In the short term, the improvement strategy may rely on the following:

1. Exploration of diversity, identification of variation by mapping natural ranges and description of phenotypic variation throughout the range;
2. Selection of species/provenances/individuals having desired qualities;
3. Mass propagation of desired individuals for reforestation or planting purposes; and
4. Conservation and maintenance of germplasm for further improvement and enhancement.

All steps can go on simultaneously. Steps 2 and 3 will bring immediate gains. Intensive efforts should also be made to carry out steps 1 and 4.

Quick production gains can be achieved by selection through faster evaluation and multiplication of superior germplasm and by utilizing them directly in plantations. In this regard, some of the following parameters may be considered for the selection work (Banik 1773).

Vegetative characters

1. External morphology

Clump nature: Thorny or *non-thorny, erect,* erect with pendulous tips, *broadly arched to clambering. Branching* throughout, only at top or *up to mid part of* culm. Leaf size, evergreen deciduous, culm colour. *Clump* congested or *open. Disease infection* (resistant/susceptible). (Note: More desirable characters are given in italics).

Growth habit and Droductivitv: Culm height, diameter, wall thickness. Culm emergence time, juvenile mortality, culm production per clump per year, clump expansion rate. Edible shoot production, shoot taste and palatability, canning ability.

2. Internal structure

Fibre characteristics: Wall thickness, cell length and diameter.

Chemical characters: Silica, cellulose and lignin contents.

Sexual characters

1. Flowering habit: Inter-seeding period, complete/part flowering, gregarious/sporadic/regular flowering. Simultaneous reproductive and vegetative growth.
2. Seed production: Sterile/fertile. Seed production capacity. Seed structure, germination, viability and storage.

The following procedures are to be followed during the selection of species/provenance/genotypes in improvement work (Banik 1993).

Exploration

This involves extensive field visits, both in natural and introduced areas of the species/provenance/genotype; collection of herbarium samples and propagules for taxonomic study and germplasm conservation, respectively; mapping of the area with details of climatic and edaphic information and identification of species/provenance. Major outputs are maps, herbarium specimens, propagules and data on the habitat.

Evaluation I (Theoretical)

Theoretical evaluation involves a listing, based on the habitat data and utilization value, of a number of species/provenances which have habitat conditions more or less similar to the proposed planting sites.

Evaluation II (Elimination trial)

The second evaluation comprises designing species elimination, provenance trial and assessing the performance of genotypes. Lay out and assess trials in nursery and field for a range of site types and with varying silviculture treatments. Analyze the national data and compare them with those of other countries, especially with those of the land of origin. Data from collaborative international trials of the species/provenances in each country are also to be analyzed. Study and compare the documented description of the species with that of the same species collected from different geographical (country) sources. Analyze the herbarium material (type specimen), and compare it with the specimen collected from different geographical (country) sources. The outputs of evaluations are data on species or their provenances, and their performance as effected by sites.

Choice of species/provenances/genotypes

Grade the species/provenances/genotypes on the basis of field performance data and the final desired use. This helps the selection of species/provenances/genotypes.

In addition to species/provenances/genotype selection, vigorously growing seedlings may be selected as high-yielding propagules. Since bamboos are reported to be highly cross-pollinating (Banik 1986; Zhang Guang-zhu and Chen Fu-qiu 1987), there is ample scope for selection of superior seedlings with desired combination of characteristics after each gregarious/sporadic flowering (Tewari 1992; Venkatesh 1984). During 1984, some vigorously growing seedlings of *Bambusa* tulda and *B.polymorpha* were identified and selected in the nursery of Bangladesh Forest Research Institute (BFRI). Field tests revealed that the growth of these seedlings were two to five times more than normal seedlings. Kondas et al. (1973) and Banik (1980) reported seedling segregation in *B.* bambos and *B.glaucescens* into grassy, grassy erect and very erect. The erect and very erect types have shown fast growth rate and more vigour with rapid culm production. Dwarf grassy type may be selected for ornamental purpose.

After selecting the suitable species, outstanding provenances, and phenotypically superior individuals, they are to be multiplied asexually so that true-to-type plants can be grown. A clone bank may subsequently be developed and the clones evaluated in multi-locational field trials.

Every bamboo growing country should adopt *in situ* conservation to maintain and protect the valuable genetic resource of natural bamboo species in their specific environments and ecosystems. Three sets of management objectives, namely, ecological, economic and social, are to be recognized in *in situ* conservation. The local people who are responsible for much of the anthropogenic pressure on the bamboo forests, must be involved in planning, management and protection of *in situ* conservation sites. Such as reserve sanctuaries should be divided into two zones – 'buffer zones and core zones. The buffer zone comprising an area immediately outside the core areas may be jointly managed with the people from adjacent villages to meet their needs. In *situ* permanent sample plots (PSP) are to be established in the core areas of different bamboo forests.

Community-based conservation, a form of *in situ* conservation, has been thriving for hundreds of years mainly because it provides direct benefit to farmers. This must be enhanced and encouraged.

Efforts aimed at arresting rapidly deteriorating resources through centralizing and protecting the genetic resources at *exsitu* conservation stands outside the natural distributions of population are important. Depending on the nature of bamboo – mainland species, peninsular species and mountainous species, three ex *situ* centres may be established in South and Southeast Asia (Anonymous 1994b).

Long-term strategy for improvement

The long-term strategy for genetic improvement aims at maximizing genetic gains in the future. There should be continuous search for genetic variability and its maintenance. Besides, attempts should also be made to establish bamboo seed stands in all bamboo-growing countries, especially in Malayan Peninsular zone since some bamboo species (Schizostachyum *brachycladum* of this zone flower frequently. Assessment of genetic variability may be pursued through carefully designed evaluation trials (Lawrence 1995) as well as through polyploidy, hybridization and mutation research.

Raising seed stands

In addition to the gregarious flowering habit, many bamboo species – such as *Bambusa bambos, B. longispiculata, B. nutans, B. tulda, Dendrocalamus* longispathus, *D. strictus, etc.* – show sporadic flowering in isolated clumps or in small groups of clumps. Brandis (1899) has recorded that B. *tuldu,* in addition to its long 20 to 30-year duration of gregarious flowering, also exhibit frequent sporadic flowering. The species also flowered sporadically on nine occasions in Chittagong within 12 years (1978-1990). B. *tulda* can hence be said to have a number of flowering genotypes. Janzen (1976) inferred that such variation is due to the different clones existing within the same species of bamboo that are slightly "out-of-phase" in flowering habit with each other. Such out-of-phase flowering clumps are the expressions of different segregation (Watanabe and Hamada 1981). Such flowering genotypes are to be identified in nature and assembled in one place. In the next flowering period these genotypes are likely to flower one by one and also in between the normal gregarious flowering period (Banik 1980, 1993).

Such centralized plots may be termed as "seed stands". *Melocanna baccifera* has started flowering in some forests of Bangladesh and this is likely to continue up to 2000 AD. During this time every year seeds can be collected from different flowering cohorts. Seedlings be raised separately and centralized by systematic year-wise plantation. Again, some bamboo species flower at different times. It will be worthwhile to collect these flowering genotypes of species and plant them in one plot. At the next flowering period, they will flower sequentially at different times and thus seed yield will be more frequent.

Unlike Indian bamboos, a number of bamboo species growing in Thailand and Malaysia are reported to flower either frequently or sporadically from time to time (Holttum 1958; Anan 1987, 1990). If all the species are grown in one place the availability of bamboo seeds will be more frequent and easier. For this purpose, regional cooperation for the exchange of seeds and other planting materials is necessary.

Induced mutation

Bamboo seeds may be irradiated the gamma rays to induce genetic changes in the seedlings. Chemical mutagens may also be used.

Induction of variability through biotechnology

Biotechnology presents potential alternatives and aids to improve cultivated bamboos. Selections for some clonal variants emphasize the chromosomal instability inherent in callus culture. When flowers are available, anther culture and embryo rescue methods can be exploited to enhance breeding. In *vitro* flowering method offers further hope (Nadgauda et al. 1990). Research on haploid culture, callus culture against stress conditions, development of tolerant cell line, etc. should also be started as a part of the long-term genetic improvement program. Action plan for increased yield and genetic enhancement are suggested (Tewari 1992).

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Vth International Bamboo Workshop &
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RECOMMENDATIONS

1. Conservation of bamboo resources require a strategy embodying in situ conservation, ex situ conservation, including community-based conservation, and focused on bamboo use.

2. In developing strategy for *in situ* conservation the following are important:

   i. Much of the heritable variation valuable in utilization is within populations. Sympodial populations may be relatively small in area; monopodial may be large.

   ii. In tropical areas bamboos are associated with forest margins and anthropogenic vegetation; in subtropical areas and more temperate areas bamboos can dominate. In uplands some species are associated with more natural forests.

   iii. It is wise to consider policy issues where communities need incentives to manage areas.

   iv. Areas to be considered should be topographically, diverse and be sited to match agro-climatic patterns of distribution of groups of target species. INBAR, IPGRI and IBA are asked to develop the appropriate strategy.

3. Ex *situ* conservation should be related to availability and exchange of materials. Seed handling and storage need to be refined. Tissue culture, especially of embryos, should be promoted as a vehicle for exchange of materials and also for long-term conservation.

4. IPGRI is also asked to develop a strategic plan for exsituconservation, which makes material available. This should include description and documentation especially of superior genotypes. It is noted that the strategic plan should embody terms of the Convention on Biological Diversity. It is

further noted that national programs have problems of sustainability and IPGRI is asked to pay due attention to this.

5. There is a need to accelerate study on the taxonomy and species relationships of bamboo gene pools and to study genetic affinities. IBA and IPGRI could accelerate field and herbarium surveys.

6. The key to sustain conservation and use is the understanding of genetic diversity (including intraspecific) and studies on the extent and distribution of genetic diversity (especially in priority species) should be promoted.

7. Socio-economic analysis of utilization systems must be used in developing conservation strategy. INBAR's research should develop a focus in this area as a matter of urgency.